SW

Vol. 34, No. 6 December, 1944

PROPERTY OF
PRINCETON UNIV
RECEIVED JAN 8 1945

Journal of Experimental Psychology

EDITED BY

SAMUEL W. FERNBERGER, ON LEAVE
FRANCIS W. IRWIN, ACTING EDITOR
UNIVERSITY OF PENNSYLVANIA

CONSULTING EDITORS

CHARLES W. BRAY, *Princeton University;* ELMER K. CULLER, *University of Rochester;* CLARENCE H. GRAHAM, *Brown University;* JOY P. GUILFORD, *University of Southern California;* FRANCIS W. IRWIN, *University of Pennsylvania;* DONALD G. MARQUIS, *Yale University;* ARTHUR W. MELTON, *University of Missouri;* CARROLL C. PRATT, *Rutgers University.*

CONTENTS

Generalization of a Scale of Values by the Averaging of Practice Effects: D. M. JOHNSON 425

A Preliminary Investigation of Form and Motion Acuity at Low Levels of Illumination: C. J. WARDEN AND H. C. BROWN 437

Differential Sensitivity to Intensity as a Function of the Duration of the Comparison Tone: W. R. GARNER AND G. A. MILLER 450

The Relation between the Foveal Intensity Threshold and Length of an Illuminated Slit: R. H. BROWN AND J. I. NIVEN 464

The Generalization of Extinction Effects within a Habit Pattern: J. M. FELSINGER 477

Experimental Transfer of Conditioning in Dogs: D. T. GRAHAM 486

A Comparison of Finger Tremor with the Galvanic Skin Reflex and Pulse: J. W. FRENCH 494

Learning as a Function of the Absolute and Relative Amounts of Work: M. E. THOMPSON 506

Controlled Temperatures and Preliminary Measures of Motivation of the White Rat: K. MOORE 516

PUBLISHED BI-MONTHLY,
BY THE AMERICAN PSYCHOLOGICAL ASSOCIATION, INC.
PRINCE AND LEMON STS., LANCASTER, PA.
AND NORTHWESTERN UNIVERSITY, EVANSTON, ILLINOIS

Entered as second-class matter, February 6, 1937, at the post office at Lancaster, Pa., under the Act of March 3, 1879

XUM

PUBLICATIONS OF

THE AMERICAN PSYCHOLOGICAL ASSOCIATION

WILLARD L. VALENTINE, *Business Manager*

PSYCHOLOGICAL REVIEW

HERBERT S. LANGFELD, *Editor*
Princeton University

Contains original contributions only, appears bi-monthly, January, March, May, July, September, and November, the six numbers comprising a volume of about 540 pages.
Subscription: $5.50 (Foreign, $5.75). Single copies, $1.00.

PSYCHOLOGICAL BULLETIN

JOHN E. ANDERSON, *Editor*
University of Minnesota

Contains critical reviews of books and articles, psychological news and notes, university notices, and announcements. Appears monthly (10 issues), the annual volume comprising about 665 pages. Special issues of the BULLETIN consist of general reviews of recent work in some department of psychology.
Subscription: $7.00 (Foreign, $7.25). Single copies, 75c.

JOURNAL OF EXPERIMENTAL PSYCHOLOGY

S. W. FERNBERGER, *Editor, on Leave*, FRANCIS W. IRWIN, *Acting Editor*
University of Pennsylvania

Contains original contributions of an experimental character. Appears bi-monthly (beginning 1944), one volume per year, each volume of six numbers containing about 520 pages.
Subscription: $7.00 (Foreign, $7.25). Single copies, $1.25.

PSYCHOLOGICAL ABSTRACTS

WALTER S. HUNTER, *Editor*
Brown University

Appears monthly, the twelve numbers and an index supplement making a volume of about 700 pages. The journal is devoted to the publication of non-critical abstracts of the world's literature in psychology and closely related subjects.
Subscription: $7.00 (Foreign, $7.25). Single copies, 75c.

PSYCHOLOGICAL MONOGRAPHS

JOHN F. DASHIELL, *Editor*
University of North Carolina

Consist of longer researches or treatises or collections of laboratory studies which it is important to publish promptly and as units. The price of single numbers varies according to their size. The MONOGRAPHS appear at irregular intervals and are gathered into volumes of about 500 pages.
Subscription: $6.00 per volume (Foreign, $6.30).

JOURNAL OF ABNORMAL AND SOCIAL PSYCHOLOGY

GORDON W. ALLPORT, *Editor*
Harvard University

Appears quarterly, January, April, July, October, the four numbers comprising a volume of 560 pages. The journal contains original contributions in the field of abnormal and social psychology, reviews, notes and news.
Subscription: $5.00 (Foreign, $5.25). Single copies, $1.50.

JOURNAL OF APPLIED PSYCHOLOGY

DONALD G. PATERSON, *Editor*
University of Minnesota

Covers the applications of psychology in business, industry, education, etc. Appears bi-monthly, February, April, June, August, October, and December.
Subscription: $6.00. Single copies, $1.25.

Subscriptions, orders, and business communications should be sent to

THE AMERICAN PSYCHOLOGICAL ASSOCIATION, INC.

NORTHWESTERN UNIVERSITY, EVANSTON, ILLINOIS

Journal of
Experimental Psychology

VOL. 34, NO. 6 DECEMBER, 1944

GENERALIZATION OF A SCALE OF VALUES BY THE AVERAGING OF PRACTICE EFFECTS

BY DONALD M. JOHNSON

University of Illinois

Many judgments are expressed in reference to a scale of values which is a product of the judge's past experience; and individual differences in judgment are often attributed to differences in the experiences from which different judges have organized their scales. If A calls Mr. X a radical and B calls the same Mr. X a conservative, the explanation usually offered is that A and B have different backgrounds. Presumably A has been exposed chiefly to conservative ideas and has organized his scale of judgment around the conservative end of the radical-conservative continuum. Hence he finds Mr. X at the radical end of his scale. B has organized his scale around the radical end of the continuum and finds Mr. X a conservative. A perceptual phenomenon, the figure-and-ground effect, operates in this case so that the object of judgment, Mr. X, stands out as figure—and will be remembered and discussed—while the two scales, as grounds, are unnoticed.

All this is quite adequate in an introductory way, and concepts such as scale of values and frame of reference have been widely used in social psychology. The next step is one of analysis and quantification. If the scale is learned, it should be possible with modern psychological techniques to control the judge's practice and to study the relation between such practice and the resulting scale. The obvious procedure is to bring several *S*s into the laboratory, give each one practice in judging a different set of objects, then to compare each *S*'s resulting scale of values with the experience (the set of stimulus objects) on which it was based. The success of such a procedure depends upon three requirements.

1. *A quantitative record of practice is necessary.* Such a measure can be approximated by using each judgment of an object as a unit of practice with that object.

2. *The laboratory practice, which is controlled, must be separated from the extra-laboratory practice, which is uncontrolled.* If the stimulus material and the experimental arrangements are quite different from the *S*'s previous experience, it is likely that the laboratory experience will be segregated as a perceptual whole relatively unaffected by transfer of previous practice effects.

3. *The scale of values must be described quantitatively.* A subjective scale, like a concept, is generalized from many particular experiences, and quantitative description of a scale is an inference from its effects on many particular judgments. The scale consists of several categories of response located along a continuum. These categories may be named in accordance with many schemes: 'large' and 'small,' A, B, C, D, E, 'very unpleasant,' 'unpleasant' . . . 'very pleasant,' 1, 2, 3, . . . 7. If the objects of judgment can be described quantitatively, the scale can be described quantitatively in the same units by computation of boundaries or limens between adjacent categories. If several weights, for example, are repeatedly judged, one at a time, in two categories, such as 'heavy' and 'light,' the distribution of judgments in relation to the stimulus continuum shows a transition zone between 0 percent frequency of use of one category for some weights to 100 percent frequency for others. (See Fig. 1.) Conventional psychophysical calculations, allowing for the variability of judgment within this transition zone, yield a mean transition point or limen between the two categories. If the judgments are made in three categories, two category limens are calculated. If the judgments are made in reference to a scale of n categories, $n - 1$ category limens are calculated. These limens locate the boundaries of each category of the scale—except at either end—in the units of the stimulus variable. Blumenfeld (**2**, pp. 393–428) has published a detailed analysis, based on such calculations, of scales of 2, 3, 5 and 10 categories.

These three requirements are approximately met in psychophysical experiments wherein absolute judgments of single stimuli are made. A general discussion of this method has been written by Wever and Zener (**5**). If a person is given a series of weights, one by one, and asked to call each 'heavy' or 'light,' he may protest at such an absolute judgment, but soon he will judge in these two categories without hesitation. Thus it may be inferred that he has constructed a subjective scale of the two categories, 'heavy' and 'light.' The purpose of the present investigation is to study the relation between category limens obtained by this method and the weights used, and to predict, if possible, where the limens will fall.

The most obvious fact, to begin with, is that the threshold between any two categories, between 'light' and 'very light' or between

'radical' and 'conservative,' is not a simple response to any one stimulus. It is a resultant or generalization of the effects of many stimulations. An averaging process seems plausible, and in fact Hollingworth developed a 'law of central tendency' to account for

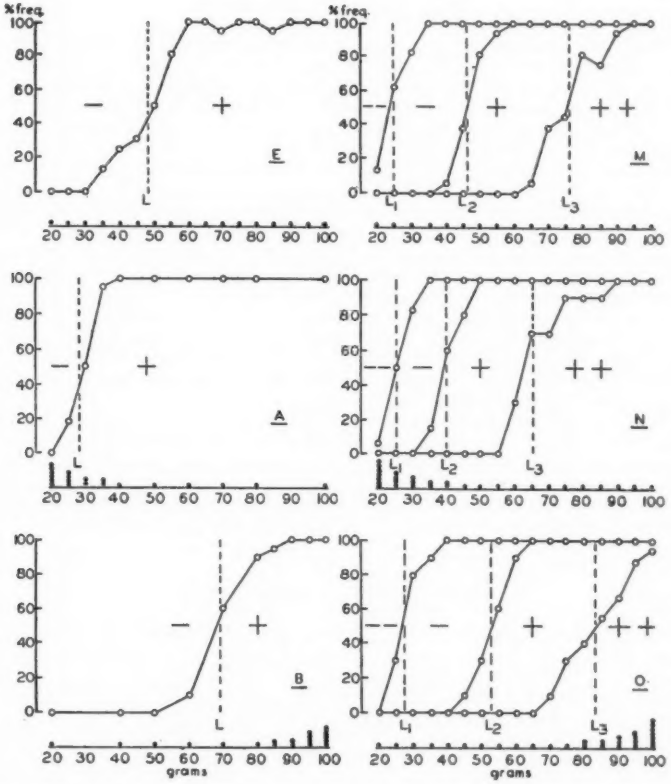

FIG. 1. Transition zones and category limens for scales of two and four categories. The solid lines are cumulative frequency curves showing the transition from categories at the left to those at the right. The broken lines are the statistically determined limens or boundaries between adjacent categories. A frequency distribution of the weights on which each scale is based is shown below each plot. Series E and M were given 16 times, the others 10. Hence each point in the plot for Series E is a percentage based on 16 judgments for every dot on the baseline. Likewise, each point in the plot for Series N is a percentage based on 10 judgments for every dot on the baseline. Vertical comparisons show the effect of skew in the distribution of stimuli.

certain systematic errors in psychophysical experiments. Woodworth (6, pp. 445–449) has brought the literature on central tendency up to date. But there are several measures of central tendency:

mean, median, geometric mean, etc. Lacking any rational basis for preferring one average to another we can only set up an experiment which will permit a choice on empirical grounds. This was done in the first experiment.

The First Experiment

Weights were used as the objects of judgment. Skew distributions were set up in order to separate mean and median. Series A was made up of these 20 weights (in grams): 20, 20, 20, 20, 20, 20, 25, 25, 25, 25, 30, 30, 35, 35, 40, 50, 60, 70, 80, 100. The mean of this series is 37.5, the median 27.5 and the geometric mean 32.6. Series B was a 'mirror image' of Series A: 20, 40, 50, 60, 70, 80, 85, 85, 90, 90, 95, 95, 95, 95, 100, 100, 100, 100, 100, 100. The mean of this series is 82.5, the median 92.5 and the geometric mean 77.7.

The weights were presented one at a time and the *S* was asked to judge each—including the first—'light' or 'heavy.' The *S* used his own manner and speed of lifting and judging. A random order for presentation was obtained by writing the numbers of the weights on cards and shuffling these before each presentation of the series. Each *S* judged the series of 20 weights 10 times (after one practice run) in a session of about an hour with a brief rest in the middle.

The *S*s were volunteers from elementary psychology classes. Five *S*s were used for Series A and 10 for Series B, because the variation was greater in Series B.

Limens were computed by simple graphic interpolation. There was no difficulty in locating each limen within an error of four gm., which is adequate for present purposes. For the five *S*s who did Series A the limens were: 26, 27, 28, 29, 38. The mean is 29.6. For the 10 *S*s who did Series B the limens were: 42, 64, 64, 68, 69, 72, 72, 76, 88, 88. The mean is 70.3. Graphs of the data for a typical *S* in each series are shown in Fig. 1.

These values permit immediate elimination of the median. No limen in Series B reached the median. The arithmetic mean can also be eliminated. It is within the range of obtained limens for each series but far above each mean limen. The geometric mean, though not close, is the best measure of central tendency thus far proposed, in the sense that it is the best predictor of the obtained means. Consideration of these results led to a theoretical interpretation of the generalization of a scale of values and a more adequate measure of the central tendency of the scale.

Mathematical Discussion

Let us begin with a simple case, and generalize it later. Two stimuli, x_1 and x_h, have been presented to an *S*, with instructions to call one 'light' and the other 'heavy.' This is the simplest sort of pattern, but a pattern nonetheless, since x_1 is light in relation to x_h, and x_h is heavy in relation to x_1. Then the *S* is given another stimulus, x_0, of such magnitude that $x_1 < x_0 < x_h$, with instructions to call it 'light' or 'heavy.' The question is: Will x_0 evoke the same response as x_1 or as x_h? From what we know of generalization along a stimulus continuum, we may assume that the central effect of stimulation with x_1, which we shall call y_1, spreads upward toward y_0, and that the effect of x_h, which we shall call y_h, spreads downward toward y_0. The tendency to equate or assimilate y_0 to y_h and thus to respond to x_0 as to x_h will be a decreasing function of the difference between y_0 and y_h, which can be expressed as $f(y_h - y_0)$, and an increasing function of the distance between y_0 and y_1, which can be expressed as $F(y_0 - y_1)$. The resultant tendency to call x_0 'heavy'

rather than 'light' can be expressed by subtracting the first expression from the second:

$$T_{(h-l)} = F(y_0 - y_l) - f(y_h - y_0). \tag{1}$$

Now if we assume that y_l and y_h spread up and down the scale in a linear way so that f and F are simple constants of proportionality, and that $f = F$, we can sum these resultant tendencies for N stimuli (y_0 is taken as a point on the scale, not as a stimulus object) and get:

$$\Sigma T_{(h-l)} = k(Ny_0 - \Sigma y_i), \tag{2}$$

where y_i means the effect of any weight. To locate the category limen, the point on the scale where the tendency to respond 'heavy' is equal to the tendency to respond 'light,' we set this quantity equal to zero and solve for y_0, finding that

$$y_0 = \frac{\Sigma y_i}{N}. \tag{3}$$

This hypothesis may be stated verbally: The category limen of a two-category subjective scale of values is the arithmetic mean of the central effects of the stimulus objects on which the scale is developed.

The next task is to find the central effect, y_i, of any stimulus, given only the stimulus magnitude, x_i. Present knowledge of receptor functioning suggests a logarithmic relation: $y = a \log x + c$. But if this assumption were a good one, the geometric means of the two series of weights in the first experiment would not be so far above the mean of the obtained limens. A correction can be introduced—in a purely empirical way—to increase the slope of this curve. A simple function of the form

$$y = a \log x - bx + c \tag{4}$$

is plausible. It is not necessary for present purposes to know the units in which y is expressed. Letting a represent a modulus, therefore, we can write a more usable equation:

$$y' = \frac{y - c}{a} = \log x - b'x. \tag{5}$$

A value of b' which satisfies the data of the first experiment reasonably well was found by cut-and-try procedures to be 0.004. This would give a limen of 30.7 for Series A and 67.9 for Series B.

We now have two equations, Equation 3 and Equation 5, for computation of the category limen for any two-category subjective scale which is based on experience with any distribution of weights within the range employed in the first experiment. For each stimu-

lus, x, used in an experiment, a y'-value can be found by Equation 5. The mean of the y'-values gives the category limen by Equation 3. This can be transmuted back into an x-value or stimulus magnitude through Equation 5.

Equations 3 and 5, which relate to 'inner' and 'outer' psychophysics respectively, merit further discussion. In a general way Equation 3 may be taken as the central mechanism by which the organism 'adjusts to' or 'gets set for' a segregated group of environmental events. There is no argument *a priori* for limiting it to the central effects of any particular kind of events. Equation 3 is based on the assumption that the influence of one y-value on another is a *linear function* of the distance between them. If this function were not linear, stimuli far from the category limen would have relatively less influence, and negative skew in a series would raise the limen while positive skew would lower it. But the data of the first experiment show that the center of a scale can be computed without regard to skew by the above procedures. (These computations are to be checked on a variety of distributions in the next experiment.) On the other hand Hull (4), in his chapter on stimulus generalization, assumes a *decay function*, and Hovland's data give this assumption strong support. The decay is proportional to 10^{-hd} where d is the distance and h is a constant—of the order of 0.01 when d is a qualitative distance and 0.006 when d is a quantitative distance. The difference between these two assumptions is not as great as it seems. It is quite likely that, when a scale is thoroughly generalized, when the patterning is complete, the decay in spread of practice effect from one part of the pattern to another vanishes, and the exponent in Hull's equation approaches zero.

Equation 5 is an empirical equation and cannot be expected to hold for stimulus magnitudes beyond the range from which it was derived. Since additional muscle groups, e.g., shoulder, legs, are brought into use as a weight increases, it is apparent that this equation is only part of a complex relationship.

An Experiment in Prediction

The discussion so far has been based on data from two series of weights. To test the general applicability of the conclusions 10 new series were set up: C, D and E were rectangular distributions; F, G and H were skew; I and J were U-shape; K and L were approximately normal. They were made up so as to give a variety of types of distribution and to yield category thresholds throughout the range of weights used in the first experiment. The weights were arranged at equal intervals so that thresholds could be computed by the summation method.

The instructions were modified in an attempt to cut down the variability shown in the first experiment. After each S had run through the weights once, he was told that he had lifted the heaviest and the lightest, that no new ones outside this range would be presented. Each S was also told not to try to remember how he had previously judged the weights but to "call them just the way they feel." Each series was judged 16 times (after the practice run), and a different S was used for each series. Otherwise procedures were the same as in the first experiment.

Table I shows the distribution of weights in each series and the limens predicted for each series by the procedures described above. Parallel to these are the limens computed by the summation method

TABLE I

COMPARISON OF PREDICTED AND OBTAINED CATEGORY LIMENS FOR TWO-CATEGORY SCALES BASED ON EXPERIENCE WITH 10 SERIES OF WEIGHTS

Series	Predicted limen	Obtained limen	SD	Error	Percent error
C 20 25 30 ··· 55	34.7	29.7	2.5	5.0	17
D 60 65 70 ··· 100	76.3	71.9	6.3	4.4	6
E 20 25 30 ··· 100	49.1	48.1	10.1	1.0	2
60					
60					
50 60					
50 60					
F 20 30 40 50 60	45.0	41.2	6.3	3.8	9
100					
100					
90 100					
90 100					
G 60 70 80 90 100	83.9	75.4	8.5	8.5	11
75					
75					
75 80 85					
75 80 85 90					
H 75 80 85 90 95 100	81.6	77.4	5.5	4.2	5
20 40					
20 40					
20 40					
I 20 25 30 35 40	28.2	26.8	4.1	1.4	5
70					
70					
70					
40 70					
40 70					
J 40 45 50 55 60 65 70	55.3	58.3	12.0	−3.0	−5
40					
40					
30 40 50					
30 40 50					
K 20 30 40 50 60	37.8	37.2	4.6	.6	2
60 70					
60 70					
50 60 70 80					
L 40 50 60 70 80 90	61.8	61.7	6.6	.1	0

from the obtained judgments and the SD's for each distribution of frequencies. The error of prediction and the error as a percentage of the obtained limen are also shown. The average error—calculated

without regard to sign—comes out as 6 percent. A similar calculation, using the mean of the weights as the predicted limen, gives an average error of prediction of 13 percent.

The predicted limens in general are too high. Only one is too low. But the correspondence is close enough to justify confidence in the above method of predicting the category limens. One question raised above, the question of linearity of spread of practice effect along the scale, can be answered by comparing the errors of prediction for symmetrical and asymmetrical series. Series C, D, E, I, K and L are symmetrical. Mean percentage error of prediction for these is 5.3. Series F, G and J are negatively skewed. Mean percentage error of prediction for these—when summed algebraically—is 5.0. Although the number of series in this comparison is not large, the skew in some series is great. In the first experiment also both series were highly skew. Hence it appears safe to conclude that the contribution of each practice effect, or y-value, to the central tendency of the scale of values is a linear function, or something close to a linear function, of the distance from the central tendency.

Application to Published Data

A search of the literature yielded two papers which give data on lifted weights by the method of absolute judgment. Wever and Zener (**5**) publish results for six observers using weights of 88, 92, 96, 100 and 104 grams, all judged equally often. Equations 3 and 5 predict the category threshold of a two-category scale based on experience with these five weights at 94.0. Unfortunately for our purpose, Wever and Zener had their observers judge in three categories, 'one,' 'two' and 'three,' but the point of subjective equality which they compute may be taken as approximately equal to that obtained by the two-category method. Their Table I, page 482, gives the six PSE's as 93.2, 93.5, 94.8, 94.8, 95.5 and 94.5. The mean of these values is 94.4, a trifle higher than the predicted value.

Wever and Zener also show PSE's for two observers who judged the weights 84, 88, 92, 96, 100, 104 and 108 in terms of 'light,' 'medium' and 'heavy.' The predicted category threshold is 93.5. The two PSE's shown by Wever and Zener in Table II, page 484, are 94.8 and 93.2.

Fernberger (**3**) has published PSE's obtained by absolute judgments in terms of 'light,' 'intermediate' and 'heavy.' The weights were the same as the second series used by Wever and Zener, and our prediction would be the same, 93.5. Fernberger's PSE's, as given in his Tables I to VIII, pages 568–570, are 96.01, 87.91, 92.04, 92.57, 94.58, 91.71, 90.66 and 90.38, with a mean of 92.0 The mean for

Wever and Zener's two observers combined with Fernberger's eight is 92.4. This compares fairly well with the predicted value of 93.5.

Scales of n Categories

The two-category scale is a special case, hardly meriting the term 'scale.' It would be more suitable, perhaps, since the one limen between the two categories is the only determinate point on the scale, to speak of a 'norm' of judgment rather than a 'scale' in this case. But the theory developed for the two-category case may be extended

TABLE II

Predicted and Obtained Limens for Scales of Four Categories Based on Experience with Three Series of Weights

	Series	L_1	L_2	L_3
M	Predicted	27.9	49.1	80.8
	Obtained—Mi	36.6	59.4	85.4
	No	24.4	46.6	76.3
	Mean	30.5	53.0	80.9
N	Predicted	23.6	35.3	74.3
	Obtained—Kr	24.1	44.5	77.0
	Da	25.6	39.8	65.5
	Mean	24.9	42.2	71.3
O	Predicted	29.8	60.2	92.5
	Obtained—Br	38.0	69.9	98.1
	Ka	27.5	53.3	83.3
	Mean	32.3	61.6	90.7

to other cases. The general principle expressed in Equation 3 is that the limen occurs at the point where the deviations on one side balance the deviations on the other. This is a well-known property of the mean, and the data reported above give considerable support to this principle for the two-category case. The principle can be generalized to other scales of value which are organized around a central tendency by assuming that the deviations from the central tendency are equally divided by the other category limens. The general principle may be written as follows:

$$\sum_{l}^{L_1} |\bar{y} - y| = \sum_{L_1}^{L_2} |\bar{y} - y| = \cdots = \sum_{L_{n-1}}^{h} |\bar{y} - y|. \qquad (6)$$

In this equation l and h refer to the lowest and highest y-values and L refers to the limens numbered serially. By this equation limens can be located only between limiting y-values. Assuming random variation in judgment the most probable value of each limen in x-units can be determined by linear interpolation between the values given by Equation 5.

The assumptions made in determining several limens along a scale

of n categories by this equation are the same as those made above in determining one limen, plus the new assumption that the scale is organized around a central tendency. This last assumption—which is almost self-evident in the two-category case—seems most plausible for scales in which the categories are named in reference to a center, e.g., 'very light,' 'light,' 'heavy' and 'very heavy.' Hence this sort of four-category scale was used in the test of Equation 6.

Three series of weights were set up. M was a rectangular series. N was a series with positive skew. O was a series with negative skew. The distributions may be seen in Fig. 1. Two *S*s were used for each series. Series M of 17 weights was presented to each *S* 16 times. Series N and O of 30 weights each were presented 10 times. Instructions and procedures were the same as above. Predicted and obtained results may be seen in Table II. Typical data are graphed in Fig. 1.

The agreement between predicted limens and means of the two obtained limens is rather close. The average discrepancy in predicting these nine limens is 6 percent of the obtained values. Such a discrepancy could easily be accounted for on a sampling basis, as the variation between two *S*s judging the same weights is large. Hence, Table II gives considerable support to the general principle and assumptions discussed above.

It is pertinent to inquire at this point if any other principle will predict these limens equally well. It is plausible to suppose, for example, that a scale would be organized so that equal numbers of stimulus objects are placed in each category. If this were so, each category of a four-category scale would contain 25 percent of the weights, and L_1, L_2 and L_3 would coincide with Q_1, Q_2 and Q_3. Estimating the nine limens of Table II by this procedure yields discrepancies as high as 67 percent and an average error of 20 percent. Hence this procedure can be discarded.

Another plausible assumption is that the scale is constructed so that the frequency of use of each category is a normal probability function of the subjective scale. Recommendations for the use of a rating scale are often made on this basis. Assuming six SD's under the probability curve and alloting these to four categories would locate the limens at the 7th, 50th and 93rd percentiles. Computing limens by this procedure leads to absurd results for the skew series and an average error of 23 percent. Hence this procedure also can be discarded.

General Implications

The most important conclusion to be drawn from these experiments is that a scale of values is a pattern which, under some condi-

tions at least, has its center at a determinate average and other characteristic points at determinate distances from this average. It is at least plausible that this principle, expressed in Equations 3 and 6, is a general principle independent of the kind of objects being judged. From the evidence assembled by Beebe-Center (1, pp. 222–235) in connection with the principle of 'mass hedonic contrast' it can be seen that some sort of averaging process operates in the organization of scales of affective value. Similarly, the correlation between a person's judgment of social issues and his previous experience indicates that the scale of values on which he judges the issues is centered around some sort of average effect of his experiences. Just what is averaged, i.e. the relation of the central effect to the stimulus variable, is of course not a general principle, but specific to the characteristic or dimension being judged. However, the fact that people do make judgments in such categories as 'slightly ——,' 'moderately ——' and 'very ——' relatively easily and consistently without special training indicates that the central effects out of which the scale is organized do have a definite relation to the objective events. The method used in deriving Equation 4 is one method of working out such a relation.

Methodological Implications

This paper deals with a problem in the psychology of learning. The problem is not, however, one of rate of learning a preassigned pattern of response, but the larger problem of why one pattern is learned rather than another. Research on this problem requires that the patterns be quantitatively described so that they can be differentiated from one another and related to the conditions of practice. Quantitative description of one particular pattern, a scale of values, in units of stimulus magnitude can easily be accomplished by conventional methods. Other patterns can be similarly described in units of stimulus magnitude. A concept, for example, can be quantitatively defined. Mi, in judging Series M, used a concept of 'light' which included, on the average, weights between 36.6 and 59.4 gm. (See Table II.) From the raw data it can be determined that her concept 'light' covered a range from 35 to 75 gm. and that its mean was at 50. In reference to the stimulus dimension, therefore, her concept of 'light' was skew. Concepts such as 'apple' and 'dax' could be similarly analyzed, in several dimensions if necessary.

In studying the relation between the outcome of practice and the conditions of practice there is a definite advantage in being able to express the dependent and independent variables in the same unit. In the present experiments, for instance, the practice, judging weights, can be accurately recorded, both in amount and kind. The results,

the obtained limens between adjacent categories on the scale of values, are calculated in the same unit. An attempt to fit a mathematical function to the relation between the two can thus ignore the constants which express the difference in unit and origin.

It is encouraging to note that the second of the three requirements discussed above, the requirement that the laboratory experience be perceptually segregated from the pre-laboratory experience, seems to be met by the set-up of this experiment. In fact, during rest pauses the *S*s would often move a chair or lift a book without apparent effect upon their scales of value based on lifting the stimulus weights. The conditions which permit such perceptual grouping could be determined by the techniques used in this experiment, and knowledge of such conditions would contribute to psychological understanding of *relevance*, an almost untouched problem in the psychology of judgment. It would be impossible to summate practice effects for a person's experience with a 60-gm. weight if his lifetime, or even recent, experience were relevant.

Summary

The investigation reported here begins by examining the problem of the learning of a scale of values. It is assumed that judging stimulus objects one by one—the method of absolute judgment—constitutes controlled practice with these objects and that the scale of values on which these objects are judged has a determinate functional relation to such practice. Alternate experimentation—with weights as the objects of judgment—and theorizing lead to an empirical equation between the magnitude of a weight and the central effect of judging the weight, and to a rational mathematical statement of the organization of the central effects of judging any series of objects into a scale of values. Computations on the basis of these principles predict limens for a variety of two-category and four-category scales which agree rather well with the empirical values. The assumptions involved in this kind of research and the applicability of these principles and methods to judgments of other material are discussed.

(Manuscript received May 5, 1944)

References

1. Beebe-Center, J. G. *Pleasantness and unpleasantness.* Van Nostrand, 1932.
2. Blumenfeld, W. Urteil und Beurteilung. Arch. ges. Psychol. Dritter Ergzbd., 1931.
3. Fernberger, S. W. On absolute and relative judgments in lifted weight experiments. *Amer. J. Psychol.*, 1931, **43**, 560–578.
4. Hull, C. L. *Principles of behavior.* Appleton Century, 1943.
5. Wever, E. G., & Zener, K. E. The method of absolute judgment in psychophysics. *Psychol. Rev.*, 1928, **35**, 466–493.
6. Woodworth, R. S. *Experimental psychology.* N. Y.: Holt, 1938.

A PRELIMINARY INVESTIGATION OF FORM AND MOTION ACUITY AT LOW LEVELS OF ILLUMINATION *

BY C. J. WARDEN AND H. C. BROWN [1]

Columbia University

INTRODUCTION

There has been relatively little experimental work reported on the problem of motion perception in either man or animal. Much more attention has been given to such other visual functions as brightness, form and color. Most of the work on form perception has been done at photopic levels of illumination in the foveal or parafoveal regions. The work on form and motion has recently been reviewed by Kennedy (4), Klein (5), Lit (6), and Ross (7).

Our main interest in the present connection is in the relationship between form and motion acuity. In 1942, Klein (5) made a study of this relationship at a photopic level of illumination (4.9 foot-candles) in this laboratory. He secured thresholds for both motion and form acuity at various points on the retina out to about 60 degrees displacement from the fovea, in the nasal quadrant. He found a very close correspondence in threshold values between these two functions of spatial discrimination.

The present problem was planned to determine whether or not the same general relationship held at scotopic levels of illumination. There has been some controversy on this point, as indicated in the review of the field by Klein. We quote:

> Hecht and Wolf . . . assumed in their experiments a close parallel between the two functions, utilizing responses to movement as indices of acuity for stationary contours in insects. This is expressed in the latter study by the assertion that "if visual acuity varies with illumination, then the capacity to respond to these movements in the visual field will depend on the illumination and the size of the pattern." (Klein, 5, p. 13.)

On the other hand, Graham and Hunter (1) secured results which do not seem to agree with this assumption. Somewhat later, Hecht and Wald (3) criticized the work of Graham and Hunter, and in-

* The Animal Laboratory, Department of Psychology.

The work described in this paper was done under a contract recommended by the Committee on Medical Research, between the Office of Scientific Research and Development and Columbia University.

[1] The senior author was Responsible Investigator and the junior author Professional Scientific Assistant on this project (OEM cmr-264).

sisted that there is a close correspondence between the form and motion functions. In view of this controversy, the need for further systematic work is clear.

In addition to the strictly scientific aspects of this study, the investigation is also related to the practical problem of the selection of night-fliers. Before setting up the main project, relating to individual differences in motion acuity, a certain amount of exploratory work was necessary. Some of the main points that had to be settled first were: (1) the devising of an appropriate stimulus, (2) the selection of the proper levels of illumination within the scotopic range, encountered in night-flying and (3) the development of criteria, procedure, instructions, etc. The present paper represents the results secured in the process of standardizing the motion acuity test for determining individual differences. In a forthcoming paper, the findings on individual variations in scotopic motion acuity will be reported.

Apparatus and Method

The apparatus described here was used in testing both form and motion acuity. The only difference was that the stimulus was stationary in the former case, and rotating in the latter. The same *S*s were employed in both tests. The specific procedure followed in testing the two visual functions differed in certain respects, and will be described separately in later sections.

Subjects.—A description of the *S*s is given in Table I. All four were graduate students in

TABLE I

Subjects

Subject	Age	Sex	Snellen ratings		
			Right	Left	Both
A	24	M	20/15	20/15	20/15
B	22	M	20/15	20/15	20/15
C	26	M	20/10	20/15	20/10
D	37	F	20/20	20/40	20/20

psychology, and had been well trained in visual discrimination work. Measures of form and motion acuity were made on the right eye only. The left eye was covered by an Adjusto eye-shield, which permitted the eye to remain open, free to blink and wink, but which prevented binocular accommodation on the fixation point. As will be seen from the table, the Snellen Index was 20/20 or above in the right eye of each *S*. None of the *S*s had a history of gross visual defect. The *S*s were paid a nominal sum at the close of the experiment (approximately 26–40 hours per subject), and were well motivated throughout.

Apparatus.—A diagram of the apparatus is shown in Fig. 1. A brief description of the main units of the apparatus will be indicated below.

1. *Motor-gear-pulley system.*—(Fig. 1, *A–H.*) The purpose of this unit was to rotate the stimulus (*K*), mounted on the shaft (*F*), at the required speeds. The system was powered by a 1/20 horse-power D.C. Emerson Motor (*B*). Constant reductions in speed were obtained by a Fisher 48:1 Reduction Gear (*C*), and a pulley-belt system (*D*, *E*). The speed of stimulus rotation was computed from the reading on the chronoscope (*H*–1), which was activated through the timing system (*G*). After the general speed level was set by means of this system, gradual

changes in securing the threshold speed could be made by the *S* by manipulating the knob of the rheostat (*N*). This was necessary since the method of adjustment was used. This system had a range of speeds from 0.4 sec./rev. to 396 sec./rev., which could be further reduced by the rheostat (*N*) to a speed of 1200 sec./rev. The system was essentially the same as that employed by Klein (5) in his study of photopic motion acuity in this laboratory.

2. *Dark cubicle.*—Although the experiment was conducted in a dark-room, a complete light-tight cubicle was constructed for the *S*. The cubicle was 5 × 5 × 5 feet, with an additional elevation of one foot in the foreground, where the stimuli were presented. The cubicle was given several coats of dull black paint, and the entrance was closed in by several overlapping layers of heavy black cloth. The only illumination within the cubicle was provided by the projector unit (*Q*, *R*), set for the given level of illumination.

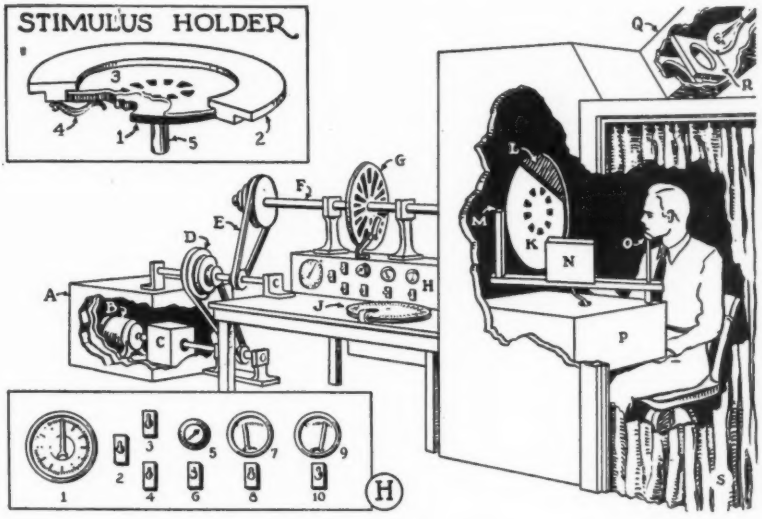

FIG. 1. Diagram of the apparatus.

3. *The illumination system.*—The stimulus was illuminated by means of a specially constructed projector (*Q*), 8 in. square and 37 in. long. The projector was set at an angle of 35 degrees above and behind the *S*, and focused directly on the stimulus. The light-tight box was painted white inside, so as to give the maximum reflectance. The light source was a 50 c.p. Mazda bulb (No. 1503) of the pre-focused spotlight variety, operating at 5 amp. The various levels of illumination were secured by the use of appropriate diaphragms. The light finally passed through two flashed opal diffusers. The projector illuminated the background about 155 degrees horizontally, and about 90 degrees vertically.

It was found that the variation in amount of the Direct Current from time to time was approximately 0.1 log. ml. It was necessary, therefore, to devise a system to stabilize the current input to the bulb of the projector. This was done by means of a modified Allen-Bradley Charging Unit. The unit kept a 6-volt Exide Storage Battery constantly charged, while the light was burning. A constant amperage was maintained through the bulb by means of a 1-ohm rheostat.

The illumination at the stimulus was measured in foot-candles, by means of a Macbeth Illuminometer. At the lower levels, this had to be done indirectly, using a series of calibrated diaphragms. The values were then converted into millilambert units for convenience. Although the projector rested at an angle of 35 degrees, the illumination of the stimulus and background was relatively uniform. As a matter of fact, the *S*s when dark-adapted were unable to

detect any difference between the top, center, and bottom of stimulus, or in the adjacent portions of the background.

4. *Perimetry technique.*—The *S* was seated in a Sturgis Ophthalmic Chair, which could be adjusted for height. The position of the head was controlled by means of the chin rest (*O*). The fixation point, a small transilluminated circle (*M*), was located 14 in. in front of the right eye, on a level with the center of the stimulus. The fixation light for the higher level of illumination (log. −1.0 ml.) was a somewhat brighter red than that used for the two lower levels. The right eye was 19.3 in. in front of the center of the stimulus. The peripheral angle settings were made by adjusting and locking the protractor disc (*J*) at the desired angle. This determined the position of the fixation point on the rotating turntable inside of the dark cubicle.

5. *The stimuli.*—The stimulus pattern for both form and motion consisted of a Landolt Ring, modified for rotary motion. Instead of a single gap, there were nine parallel-sided breaks or gaps (white areas), equidistant from each other (*K*). The stimuli were reproduced photographically on medium contrast matte paper, trimmed to 14-in. circles. These were then mounted on 14½-in. cardboard discs, 1/8 in. thick, by means of photographic dry mounting tissue. The stimuli were held in place on the bakelite disc in the manner indicated in the diagram 'Stimulus Holder' in Fig. 1. A white bristol board background, bent in the proper arc, covered the front of the cubicle surrounding the stimulus. The shutter (*L*), made of bristol board, was operated manually. A description of the stimuli is given in Table II.

TABLE II

DESCRIPTION OF STIMULI

Number	Diameter in cm.	Arc of gap in mm.	Visual angle gap in °
1	0.30	0.524	0.06
2	0.40	0.698	0.08
3	0.50	0.873	0.10
4	0.62	1.091	0.13
5	0.70	1.222	0.14
6	0.80	1.396	0.16
7	0.90	1.571	0.18
8	1.00	1.745	0.20
9	1.30	2.269	0.27
10	1.55	2.705	0.32
11	2.00	3.490	0.41
12	2.52	4.397	0.51
13	3.00	5.235	0.61
14	3.95	6.893	0.81
15	5.10	8.900	1.04
16	6.00	10.470	1.22
17	7.00	12.215	1.43
18	9.07	15.827	1.85
19	11.10	19.400	2.25

The gap or discrimen is the white square between the black wedges of the stimulus. The width of the gap is equal to 0.1745 × dia. in mm., or $\frac{\pi \times \text{dia. in mm.}}{18}$. The visual angle of the gap for each stimulus was computed by the tangent method. It is obvious that no single visual angle represents the discrimen precisely, since the distances from the eye of the inner and outer edges of the discrimen differ slightly. The diameter of the gap in mm. is probably the best representation of the discrimen.

FORM ACUITY

The aim of this section is to indicate the exact procedure used in testing form acuity, and to present the results secured. A descrip-

tion of the *Ss*, and of the stimuli used, has been given above in the previous section.

Procedure.—Tests were made at the following three levels of illumination: log. −1.0 ml. (photopic), log. −3.4 ml. (near-scotopic) and log. −4.0 ml. (scotopic). The *Ss* were dark-adapted by means of the Navy red dark-adaptor glasses. The adaptation period for the highest level was five min., and that for the two lower levels 25 min. In all cases, the *S* sat in the dark cubicle before each test for five min. without glasses, so as to become adjusted to the specific level of illumination. During this time the subject was instructed to observe the background.

The retina was explored from about five degrees from the fovea out to about 65–80 degrees, depending on the *S*. The technique employed was a modification of the traditional perimetry method used for mapping zones on the retina. Instead of the fixation point remaining stationary, the stimulus was fixed and the fixation point was moved, so as to get the proper peripheral angle (see Klein, 5, p. 48). After the ready signal was given, the *S* usually responded within a second or so, although as much as two seconds might be required. The *S* soon learned that a rapid glance at the stimulus gave the best perception. A prolonged stare caused the stimulus or the fixation point to drop out, and induced fatigue and watering of the eyes. A rest period of one or two min. was allowed between judgments. This was increased to about five min., when it was necessary to change the stimulus. During the rest periods, the *S* was instructed to relax in the chair, to look away from the fixation point, and to close and blink the eyes.

A series of stimuli, ranging in diameter from 0.30 cm. to 11.10 cm., as shown in Table II, was employed. The series was broken up into groups of four stimuli, ranging from the smallest to the largest. Within each group, the order of presentation was randomized. This method was thought to be better than randomizing the whole series, since it avoided abrupt changes in size and mental set.

A high criterion was employed in determining threshold values. Positive judgments were to be given only when the circle was seen as broken up into five or six gaps. This criterion had

TABLE III

MEASURES OF FORM ACUITY, DETERMINED BY THE METHOD OF PERIMETRY AT THREE LEVELS OF ILLUMINATION

Visual angle of gap	Log. −1.0 ml.				Log. −3.4 ml.				Log. −4.0 ml.			
	A	B	C	D	A	B	C	D	A	B	C	D
0.06	13	6	3	6								
0.08	17	8	5	8								
0.10	27	10	8	21								
0.13	32	—	11	33								
0.14	38	—	—	37								
0.16	40	17	21	39								
0.18	44	20	27	43								
0.20	54	23	36	47								
0.27	58	33	47	48	10							
0.32	71	41	48	—	8, 28	7						
0.41	85	62	55	61	35	29	7		20	10		
0.51		78	60	—	50	34	5, 30	8, 26	9, 39	6, 25		
0.61		83	67	65	60	41	37	6, 31	8, 47	33	10, 28	8, 23
0.81			74	72	66	54	48	43	6, 58	45	39	4, 36
1.04					75	66	56	52	69	59	6, 46	46
1.22						72	62	56	72	65	51	50
1.43							69	61			61	55
1.85							78	72			73	59

The values in the table represent the absolute thresholds for form acuity in terms of the degree of peripheral angle for the given stimulus employed. Where two values occur for the same size of stimulus (visual angle of gap), two threshold values were found at widely separated points on the retina.

to be met in three out of four presentations of the stimulus, at a given point on the retina. Moreover, a high degree of certainty was required of each judgment. It seems likely that the threshold values secured in this experiment lie somewhat above the absolute threshold, because of the high criterion employed.

In making a single determination, the following technique was involved. At first, the fixation point was set so that the stimulus was presented in the extreme periphery. The *S* then moved the fixation point, so as to bring the stimulus inward along the perimetric arc, in large steps (10 to 12 degrees). When the critical region was reached, the *S* made finer adjustments (retracing, if necessary) until the peripheral angle satisfying the criterion was met. The judgment was reported to the *E*, and the angular reading recorded (Protractor disc, *J*).

Results.—The results for the four *S*s are shown in Table III, and are plotted in Fig. 2. From the latter it will be apparent that, as the peripheral angle is increased, the form acuity threshold value rises. It will also be noted that, in the case of each *S*, as the level of illumination is decreased the form acuity threshold value rises. This rise is greatest at the lowest level of illumination tested (log. −4.0 ml.). The curves are regular over the range tested, although individual differences are marked (C and D). In general, these results are about what should be expected as a result of changes in retinal position and level of illumination.

Form and Motion Acuity

An attempt was made, in testing motion acuity, to duplicate as far as possible the conditions employed in the work on form acuity. The same *S*s, illumination levels, apparatus and stimulus patterns were utilized. The procedure differed slightly, however, since the *S*s were required to report on the movement of the stimulus.

Procedure.—Our main interest was to compare form and motion threshold values, at various retinal positions, under several levels of illumination. At first we attempted to follow the procedure developed by Klein (5) in this laboratory. He determined thresholds for form acuity at various retinal positions, after the manner reported above in the previous section. He then secured motion acuity thresholds at each retinal position, using stimuli of the same size as those used in the form series.

In the present experiment, we found it impossible to apply this technique. The difficulty seemed to be that our levels of illumination were much lower than that used by Klein. The rapid fading of weak stimuli at low intensities is a well known phenomenon. We attempted to secure motion thresholds, with a stimulus of a given size, at the form threshold peripheral angle. This was found to be impossible. The *S*s reported that the stimulus figure faded rapidly, and did not remain clear long enough to allow movement to be perceived. This suggests that a stimulus must exceed the form threshold before it can be perceived as moving. This is true at least for the type of stimulus used in the present study. The form aspects of the stimulus must be clearly observed for a time before a judgment of movement can be made.

After some experimentation, it was found that a stimulus would remain clear long enough to make the judgment of motion possible, when it was moved in somewhat toward the fovea. For example, with a stimulus 2.00 cm. in diameter, if the form threshold was 55 degrees of peripheral angle, the judgment of motion might not be made until the stimulus was moved into 40 degrees of peripheral angle. The amount of angular displacement toward the fovea varied from *S* to *S*, and with the level of illumination. No systematic study of the amount of this factor of retinal displacement of the stimulus was made. It is clear, however, that a direct comparison of form and motion acuity is impossible, since the same series of retinal positions cannot be employed.

It is obvious that the effect of retinal displacement toward the fovea might well be based on the factor of size. This would mean that as the stimulus is moved nearer the fovea, it increases in size and clearness to the point where a judgment of motion is possible. This can be demonstrated by the method of keeping the retinal position the same as for form, but increasing the size of the stimulus up to the point where motion judgments are possible. An attempt was made to determine whether such a size adjustment would operate in the same manner as the peripheral angle adjustment mentioned above.

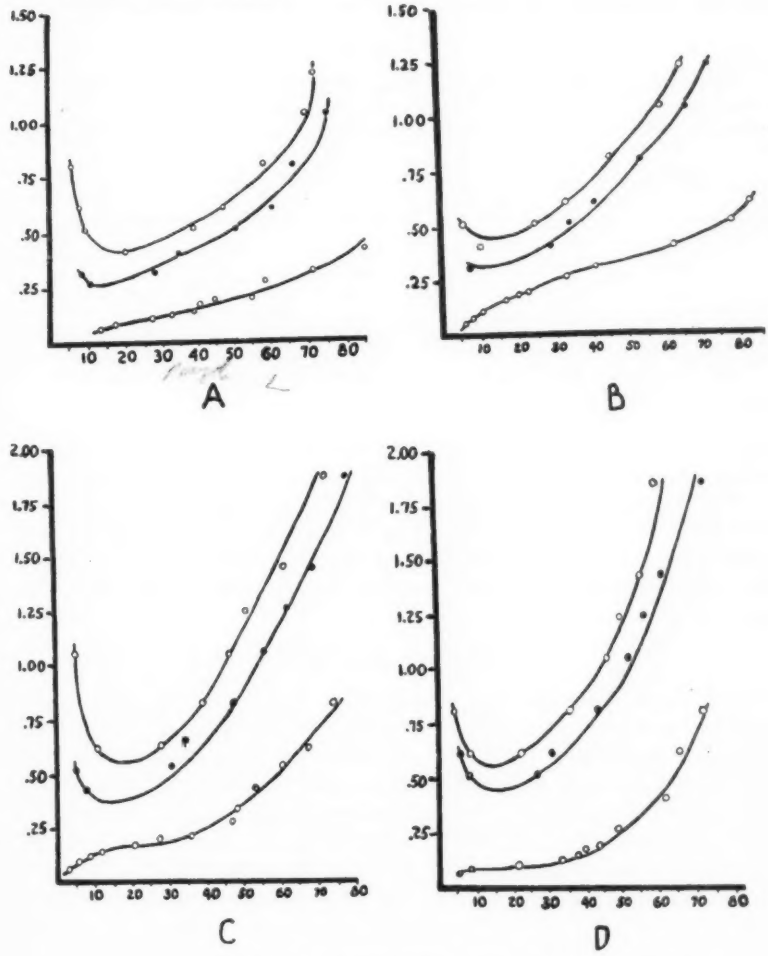

FIG. 2. Form acuity curves for the four *S*s.

The letters A, B, C and D refer to the *S*s. The retinal position, in terms of the degree of peripheral angle, is indicated on the abscissa. The width of the gap of the stimulus, in terms of degrees of visual angle, is represented on the ordinate. In each graph, the highest curve represents log. −4.0 ml., the middle curve (black dots) log. −3.4 ml., and the lowest curve, log. −1.0 ml.

Tests were made at the highest level (log. −1.0 ml.) for the following peripheral angles 7, 10, 25, 35, 45, and 55 degrees. The smallest stimulus that could be used in making satisfactory motion judgments was determined for the four *Ss* at each of the retinal positions tested. The results of these tests are shown in Table IV, and are also presented graphically in Fig. 3 (dotted line). The form

TABLE IV

THE MINIMUM GAP, IN TERMS OF VISUAL ANGLE, REQUIRED BY THE VARIOUS *Ss* TO PERCEIVE 'GOOD' MOTION OF THE STIMULUS

Peripheral angle in °	Subject			
	A	B	C	D
5	0.08		0.14	0.41
10	0.08	0.61	0.41	0.41
25	0.14	0.81	0.61	0.41
35	0.18	1.22	0.61	0.41
45	0.27	1.43	1.04	0.61
55	0.41	1.43	1.04	1.43

The data reported above were secured at the highest level of illumination employed in the experiment (log. −1.0 ml.).

acuity curves (solid line) are also plotted in the figure in order to indicate the size of the form-stimulus, for the purpose of comparison.

The increase in size was rather slight for Subject A, but quite marked for the other three *Ss*. It will be noted that as the peripheral angle increases the adjustment for size also increases. It is obvious that still larger sizes of stimuli would be necessary at the two lower levels of illumination.

MOTION ACUITY

It is clear, from the above discussion, that no direct comparison of form and motion acuity thresholds could be made under our scotopic conditions. This follows from the fact that the stimuli used in testing form acuity cannot be used in testing motion acuity. The stimuli must either be brought closer to the fovea or increased in size. The facts suggest that the retina is less sensitive to motion than to form, at rod or near-rod levels of illumination.

As stated previously, one of the aims of this experiment was to develop a standard series of stimuli to be used in the study of individual differences in motion acuity. This involved (1) the selection of a systematic series of retinal positions, and (2) the determination of the proper size of stimulus to be used at these positions.

Procedure.—It was finally decided to use the following series of peripheral angles: 7, 10, 25, 35, 45, and 55 degrees from the fovea. Each of the *Ss* was tested on a series of stimuli of different

sizes at each retinal position, in order to determine the minimum size which would give a clear perception of motion. This set of determinations was made at the highest (log. −1.0 ml.) and the lowest (log. −4.0 ml.) levels of illumination. The minimum sizes required at the lower level were considerably larger than those that would operate effectively at the higher level.

The main problem was to select a set of stimuli that would be large enough for the poorest *S* at the lowest level of illumination. This would mean that the stimuli would be adequate for

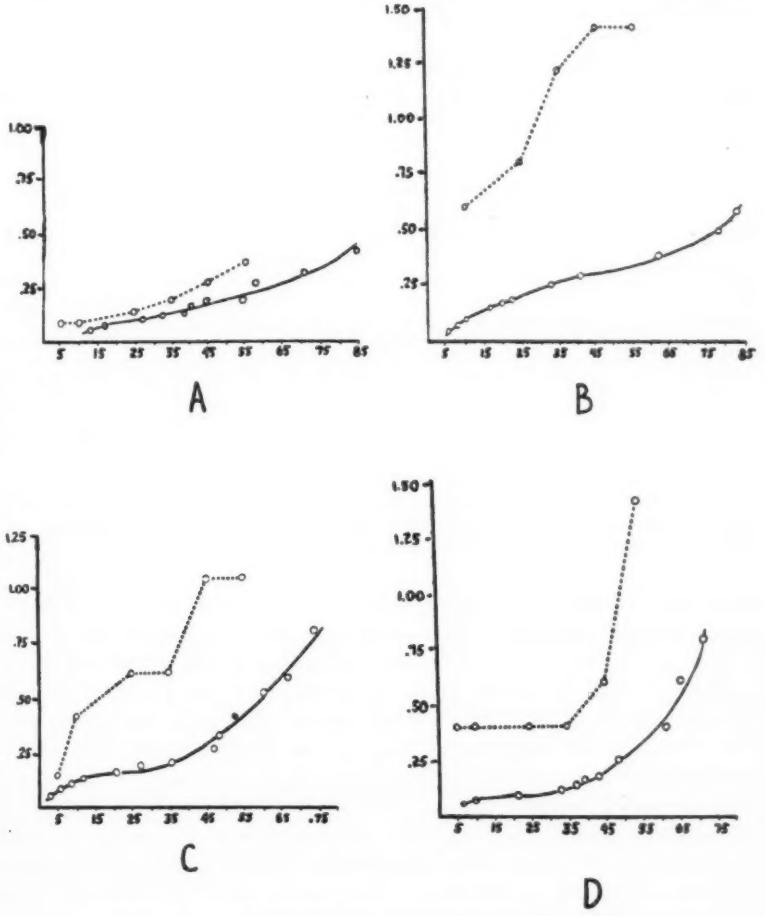

FIG. 3. A comparison of the curves for form and motion acuity.

The letters A, B, C and D refer to the *S*s. In each graph the retinal position, in terms of degrees of peripheral angle, is indicated on the abscissa. The width of the gap of the stimulus, in terms of degrees of visual angle, is represented on the ordinate. The lower curve is based on form acuity thresholds secured by perimetry at the log. −1.0 ml. level of illumination. The upper curve represents the minimum gap, in terms of visual angle, required by the *S* to perceive 'good' motion of the stimulus. The curves are plotted from the data of Tables III and IV.

all *Ss*, and actually larger than necessary for the better *Ss*. Since Subject C required the largest set of stimuli, this set was chosen as the standard stimulus series. A description of these stimuli will be found in Table I (Nos. 15–19). Stimulus No. 15 was used at both the 7- and 10-degree retinal positions. It may be pointed out that this set of stimuli was, on the average, about 89 percent larger than the series of form stimuli used by Subject C. After selecting the standard series of stimuli, a check test was run on the other three *Ss* to determine whether or not the stimuli were *too large* for good motion judgments. The set was found to be entirely satisfactory for all *Ss* at all three levels of illumination.

Results.—The results of the tests of motion acuity on each of the four *Ss* are given in Table V. It will be seen from the table that the

TABLE V

MEASURES OF MOTION ACUITY AT VARIOUS RETINAL POSITIONS FOR THE THREE LEVELS OF ILLUMINATION TESTED

Visual angle of gap in °	Peripheral angle in °	Log. −1.0 ml.				Log. −3.4 ml.				Log. −4.0 ml.			
		A	B	C	D	A	B	C	D	A	B	C	D
1.04	5	0.032	0.106	0.047	0.016	0.129	0.131	0.212	0.094	0.188	0.200	0.471	0.106
1.04	7	—	—	0.071	0.024	0.153	0.141	0.235	0.071	0.200	—	—	—
1.04	10	0.051	0.118	0.082	0.035	0.188	0.159	0.235	0.047	0.224	0.176	0.353	0.047
1.22	25	0.071	0.141	0.129	0.028	0.188	0.176	0.329	0.094	0.306	0.235	0.541	0.106
1.43	35	0.071	0.176	0.176	0.042	0.235	0.271	0.424	0.106	0.306	0.282	0.659	0.129
1.85	45	0.094	0.212	0.259	0.060	0.329	0.321	0.624	0.141	0.400	0.329	0.847	0.165
2.25	55	0.141	0.282	0.424	0.076	0.412	0.393	0.812	0.176	0.518	0.435	1.121	0.212

Each value in the table represents the absolute threshold for motion acuity in terms of the degree of visual angle per sec. A stimulus of the same size (1.04°) was used for three retinal positions (5, 7, and 10 degrees of peripheral angle).

same size of stimulus (Standard Series) was used for each *S* at the proper retinal position. The results on motion acuity are plotted in Fig. 4. The curves are regular for each *S* at each level of illumination. It will be noted that, in general, as the peripheral angle increases, the value of the motion acuity threshold rises regularly. This rise is more apparent in the curves for the scotopic levels of illumination than for the curves of the photopic level. In the latter case, the curves tend to turn downward somewhat as the fovea is approached. This suggests that motion acuity at photopic levels is greater in the fovea than elsewhere. Under scotopic conditions, however, the trend is different. The curves show an inflexion point at about 10 degrees of peripheral angle, and turn sharply upward as the fovea is approached. From the 10-degree retinal position outward, the curves rise more gradually, but reach a higher level in the periphery (55 degrees). These findings indicate clearly that motion perception under scotopic conditions is more acute at about 10 degrees of peripheral angle than either in the periphery or nearer to the fovea.

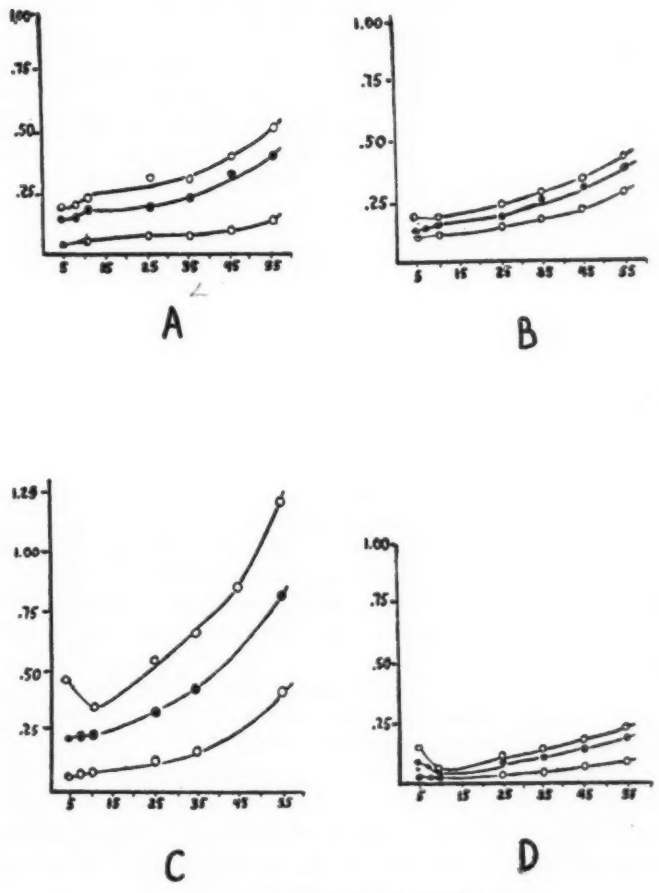

FIG. 4. The curves for motion acuity.

The letters A, B, C and D refer to the *Ss*. The retinal position, in terms of degrees of peripheral angle, is indicated on the abscissa. The rate of movement, in terms of degrees of visual angle per second, is represented on the ordinate. In each graph, the highest curve represents log. −4.0 ml., the middle curve (black dots) log. −3.4 ml., and the lowest curve log. −1.0 ml.

SUMMARY AND CONCLUSIONS

This present report covers an investigation of form and motion acuity at low levels of illumination. It should be regarded as preliminary to the study of individual differences in scotopic motion acuity to be reported in a later paper.

Four graduate students, well-trained in visual discrimination work, with a Snellen Index of 20/20 or better in the right eye, were used. Tests of form acuity were made at various retinal positions, ranging from 5 degrees to about 80 degrees of peripheral angle. Motion acuity was tested at the following peripheral angles: 5, 7, 10, 25, 35, 45, and 55 degrees. A full set of determinations for both form and motion acuity was made at three levels of illumination: log. −1.0 ml. (photopic), log. −3.4 ml. (near-scotopic), and log. −4.0 ml. (scotopic).

The major findings of this study may be summarized as follows:

A. Form acuity

1. The form acuity threshold value rises consistently as the peripheral angle is increased, within the limits tested.

2. The form threshold value rises as the level of illumination is decreased. This held true for all Ss.

B. Form and motion acuity

1. It was found impossible to compare form and motion acuity directly at various retinal positions. The stimuli used in obtaining the form acuity threshold values could not be used in securing motion thresholds at the corresponding retinal positions. Stimuli of form threshold size tended to fade out before a judgment of motion could be made.

2. In order to secure motion thresholds, it was necessary either to move the form stimulus nearer to the fovea, or to increase the size of the stimulus at a given retinal position.

C. Motion acuity

A sufficiently large set of stimuli were selected and motion thresholds obtained at 5, 7, 10, 25, 35, 45, and 55 degrees of peripheral angle.

1. The motion acuity threshold rises as the peripheral angle is increased, and as the level of illumination is decreased, the same as in form acuity.

2. Scotopic motion acuity is more acute at about 10 degrees of peripheral angle than nearer the fovea or in the more distant periphery investigated.

(Manuscript received May 9, 1944)

BIBLIOGRAPHY

1. GRAHAM, C. H., & HUNTER, W. S. Thresholds of illumination for the visual discrimination of direction of movement and for the discrimination of discreteness. *J. gen. Physiol.*, 1931, 5, 178–190.

2. HECHT, S., & WOLF, E. The visual acuity of the honey-bee. *J. gen. Physiol.*, 1929, **12**, 727–760.
3. HECHT, S., & WALD, G. The visual acuity and intensity discrimination of Drosophila. *J. gen. Physiol.*, 1934, **17**, 517–47.
4. KENNEDY, J. L. The nature and physiological basis of visual movement discrimination in animals. *Psychol. Rev.*, 1936, **43**, 494–521.
5. KLEIN, G. S. The relation between motion and form acuity in parafoveal and peripheral vision and related phenomena. *Arch. Psychol.*, 1942, No. 275. Pp. 71.
6. LIT, A. A study of peripheral form acuity under scotopic conditions. Master's thesis, Col. Univ., 1943. Pp. 48.
7. ROSS, S. Motion perception at various levels of illumination in monkeys and children. *Arch. Psychol.*, 1943, No. 288. Pp. 31.

DIFFERENTIAL SENSITIVITY TO INTENSITY AS A FUNCTION OF THE DURATION OF THE COMPARISON TONE

BY W. R. GARNER AND G. A. MILLER

Harvard University

INTRODUCTION

A basic assumption in the recent development of the quantal theory of sensory discrimination has been the existence of fixed neural units which must be activated to produce a discrimination of stimulus change. In the original article on quantal theory, Békésy (2) assumed that this fixed neural unit is a single additional fiber. Later writers, however, have found this concept to be inadequate and write of the neural unit as a group or patterning of neural elements (7, 12). They adopt the somewhat ambiguous term, *neural element*, in order to leave open the question of whether the discrimination depends upon an increment in the number of neurons firing or in the number of impulses passing along the nerve. Stevens and Davis (9) have shown that auditory loudness, at least, is correlated with the number of neurons firing, and for the purposes of this paper that assumption can be made.

The concept of the fixed neural unit for the absolute and differential thresholds has found advocates in other branches of sensory psychophysiology. Hecht (5) has been so explicit as to state that the variability of the psychometric function for the absolute visual limen is a result of variability in the stimulus and not in the sensitivity of the organism. Wald (13) has also presented reasons for believing that the absolute visual limen is fixed, and Crozier (3) has advocated the concept for both the differential and absolute limens.

If the concept of a neural quantum implies a similar constancy in the stimulus change necessary for the activation of the quantum, then it contradicts the known variability of the differential threshold measured in terms of the stimulus. This apparent contradiction is clarified when we realize that the neural response is not to a stimulus intensity alone, but to a stimulus intensity over a period of time. Time—along with frequency and intensity—is an important parameter in the determination of the differential threshold to intensity. It is not sufficient to state merely that, with a given frequency and a

given intensity or loudness level, the differential limen to intensitive change is such-and-such a value: the duration of the comparison tone must be included as one of the parameters. If the duration of the standard tone is very short (i.e., shorter than that necessary for complete integration), then that duration also becomes an important parameter. Thus, although one may be justified in assuming the constant neural quantum, or even a constancy of the sensory experience correlated with the neural quantum, one is not justified in assuming a constancy of the stimulus value necessary for the activation of the neural quantum, if the stimulus value is measured only in terms of intensity.

If time is included as an important parameter, the problem changes to the determination of the nature of the temporal integration of the nervous system—whether it is linear, or logarithmic, or whether it can be stated in any known mathematical relationship. Although this exact relationship is as yet not known, it can be said in general that the longer the duration, the less the increment in intensity necessary for discrimination.

In the field of vision there have been many more attempts to solve the problem than in the field of audition. The Roscoe-Bunsen law ($I \times t = k$), long thought to apply, has been abandoned on account of its assumption of perfect integration over a period of time. Another recent attempt to show the relation between time and intensity in the field of vision has been made by Crozier (3) who states that the quantity $I \times t$ passes through a minimum rather than remaining constant because of two factors.[1] (1) An adaptation process goes on simultaneously with the integration, thus making the measured or resultant integration non-linear. Since the adaptation process is logarithmic, this factor can be rectified by plotting the abscissa on a logarithmic scale. (2) The variability of the thresholds of the neurons involved in any discrimination is in the form of the normal distribution. Thus, any curve which is a measure of the integration of the neural elements as a function of log t (to rectify the adaptation process) should be in the form of the normal probability integral. With respect to this theory, it may be stated that Crozier has produced considerable empirical confirmation.

In the field of audition there have been relatively few attempts to determine the relation between time and intensity. Békésy (1) reported one relation between the loudness and time of relatively short

[1] For a more complete discussion of this theory, and for the derivation of the equations used by Crozier, see Crozier (3) and Morgan (8). Only one paper by Crozier has been referred to here, since it is the paper which presents his theoretical position in relation to this specific problem. He has used the theory with wide application for both time and intensity. For further references on the theory, see Morgan (8).

tones. He found that

$$\log I = k \log t + C,$$

the constant k being negative, such that when I, measured in decibels, is increased, t is decreased logarithmically. Lifshitz (**6**) later reported an integral relationship, stated in the form

$$t \log I = k.$$

This equation states a linear integration of intensity measured in decibels over a short period of time. These two experiments were, however, not directly comparable, since Békésy was measuring the intensity required to keep constant a loudness with tones less than 0.1 seconds in duration, while Lifshitz was measuring the intensity necessary to equate the apparent time of one tone of 690 msec. or less to another tone of a given intensity and a duration in the same range. When loudness is used as a variable to keep the apparent duration of a tone constant, as Lifshitz did, it is not an adequate measure of the sensitivity of the organism to intensity since loudness and apparent duration may vary or be held constant independently. Thus, although the data of Lifshitz are much more extensive than the data of Békésy, we have only the latter's experiment as a definite attempt to determine what effect the duration of a tone has on the sensitivity of the organism to intensive changes.

We find, then, that, although we can assume a neural quantum, we cannot assume any constancy of quantitative change in the stimulus necessary to activate an additional neural quantum. Furthermore, there have been practically no attempts to determine the effect of the duration of a tone on the size of the differential limen to intensity in the field of audition. The purpose of this paper thus becomes twofold: first, to determine the range of the stimulus intensities over which the differential limen may vary when it activates one neural quantum, and secondly, to determine, insofar as possible with psychological data, the nature of the neural integrative process.

Apparatus and Procedure

A schematic diagram of the apparatus used appears in Fig. 1. The oscillator is that described by Stevens and Gerbrands (**11**). Following the oscillator in the system was an attenuator, calibrated in decibel steps, the output of which was shunted by two series resistances, one of which (R_1) remained constant at 200 ohms, and the other of which (R_2) was variable. The resistances were supplied by two General Radio Decade Resistance boxes, types 603-L and 602-J. Across the variable resistance a timer was placed, such that it could short out or put in that resistance. The operation of this timer will be described in more detail with reference to the procedure used. After the shunt were high and low pass filters, General Radio type 830, the output of which fed into an impedance matching transformer, which in turn fed into a Western Electric 711A type earphone for monaural listening. At different times in the experiment 500 and 1000 cycle filters were used, and for each frequency used the oscillator was set to give maximum output as measured by a cathode-ray oscilloscope.

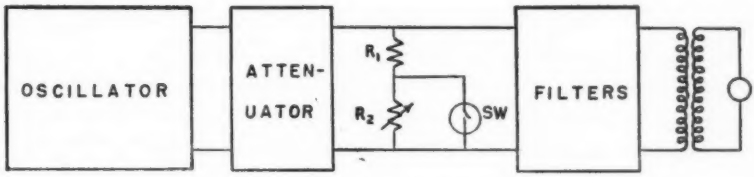

FIG. 1. Schematic diagram of the apparatus.

The increment in intensity is supplied by adding variable resistance to the circuit. Normally this part of the circuit is shorted out.

The timer used was calibrated in milliseconds, and operated a relay such that the variable part of the shunt resistance was shorted out except for that period when the increment was added to the base tone. When the shunt is increased, the intensity output at the phones is increased, and the ratio of this increment to the base intensity can be calibrated accurately as a function of the added resistance of the shunt,[2] provided the internal impedance of the oscillator and the matching impedance of the transformer are known. These were each 500 ohms.

The 200 ohms was in the shunt at all times, thus establishing the base level of the tone, which was on continuously during the measuring of the ΔI. The increment is added as a change from this base tone once every four sec., with durations of from 20 to 750 msec. The filters used fixed the time of build-up for the increment at 10 msec., so that the increment was at maximum intensity for the stated time less 10 msec. The time of decay of the tone was also 10 msec.

For each series of measurements, the absolute limen of *O* was determined and the attenuator set to the desired sensation level. After a single determination of the threshold, the intensity was held constant for each measure of the series, a procedure which seemed preferable to an attempt to keep the sensation level constant.

For the actual measure of each differential limen, the timer was set at some determined duration of the comparison tone, and was held constant for the determination of that limen, thus making time the independent variable and intensity the dependent variable. The resistance of the variable portion of the shunt was then set for some value, and *O* listened to the increments in a sound-insulated room until he felt ready to respond. When *O* felt ready, he depressed a telegraph key which started one counter recording the number of increments presented. Whenever he heard an increment, he pressed another telegraph key which operated a second counter recording the number of increments heard. If the response to increments heard did not occur within one sec. after the presentation of the increment, *E* took note of it and subtracted it from the total score as an error. After the first counter (recording the number of increments presented) had recorded 25 such presentations, *E* signalled *O* to stop judging. *E* then set the variable shunt resistance at some other value, and the procedure was repeated until 100 judgments had been made at from six to nine values of resistance. *O* was allowed a rest after every 20 or 30 min. This method is essentially that used by Stevens, Morgan, and Volkmann (12).

The data from each such measure of the differential limen were then fitted to a straight line by the method of least squares, and the 50 percent point taken as the most reliable point on the function (7). The fitting was done with values of resistance, since the function relating $\Delta I/I$ to the variable resistance was linear for the range used. The value of resistance determined as the 50 percent point was then used to calculate the actual $\Delta I/I$ ratio.

This procedure was repeated for each determination of a differential limen. The data presented were obtained over a period of two months, after each *O* had had at least a month of practice. This practice consisted in each *O*'s having provided data for approximately 30 psychometric functions of the type from which these data come.

[2] If the oscillator is regarded as putting out a voltage E′, then this total voltage drop will be across the internal impedance of the oscillator plus the matching impedance of the transformer in parallel with the shunt resistance. The voltage drop across the output impedance in parallel with the shunt will be proportionate to that resistance divided by the total resistance across which the true voltage E′ must drop. As resistance is added to the shunt, the voltage drop across the output will increase, and the ratio of two such voltages can be easily computed.

Results

Three complete curves relating the size of the differential limen to the duration of the comparison tone were obtained for each *O*. The first was found for 500 c.p.s., 40 db. of sensation level, the second for 500 c.p.s., 70 db. of sensation level, and the third for 1000 c.p.s., 40 db. of sensation level.

The results are presented in Table I, and also in Fig. 2. The

TABLE I

Differential Sensitivity to Intensity ($\Delta I/I$) as a Function of the Duration of the Comparison Tone

Time (msec.)	500 c.p.s.—40 db.		500 c.p.s.—70 db.		1000 c.p.s.—40 db.	
	GAM	WRG	GAM	WRG	GAM	WRG
20	.0999	.1213	.0342	.0329	.0692	.0816
35			.0334	.0324	.0668	.0815
40	.0937	.1054				
50			.0302	.0317	.0668	.0786
75	.0753	.0889	.0276	.0289	.0592	0.681
100	.0660	.0751	.0246	.0272	.0548	.0547
200	.0535	.0562	.0198	.0241	.0395	.0460
300	.0485	.0503	.0181	.0222	.0336	.0381
400	.0456	.0500	.0172	.0208	.0299	.0368
450	.0422	.0462				
500	.0426	.0489	.0168	.0201	.0288	.0344
750	.0396	.0446	.0168	.0196		

smoothed curves of Fig. 2 were secured by fitting the data visually, and were not obtained with specific theoretical considerations in mind. The actual voltage ratios obtained in this experiment ranged from .016 to .12 for the whole of the data. It can readily be seen by an analysis of the data in either graphical or tabular form that the ratio of the increment of I to I as measured in terms of the stimulus intensity may vary by as much as a factor of three when the time of the comparison tone varies from 20 to 750 msec. That is, the intensity necessary to activate one additional neural element, or to produce the judgment of one j.n.d., may vary over a considerable range when the time of the stimulating tone is not held constant.

In these measures, the 50 percent point was used, as mentioned above. This choice was made because the 50 percent point is a more stable point on the psychometric function than the point actually measuring the intensity to activate one quantum, which is the zero percent point (7). It should be obvious that the use of the 50 percent point as the measure of the differential limen does not change the relative range over which the stimulus intensities may vary, since the 50 percent point represents the quantal point multiplied by a con-

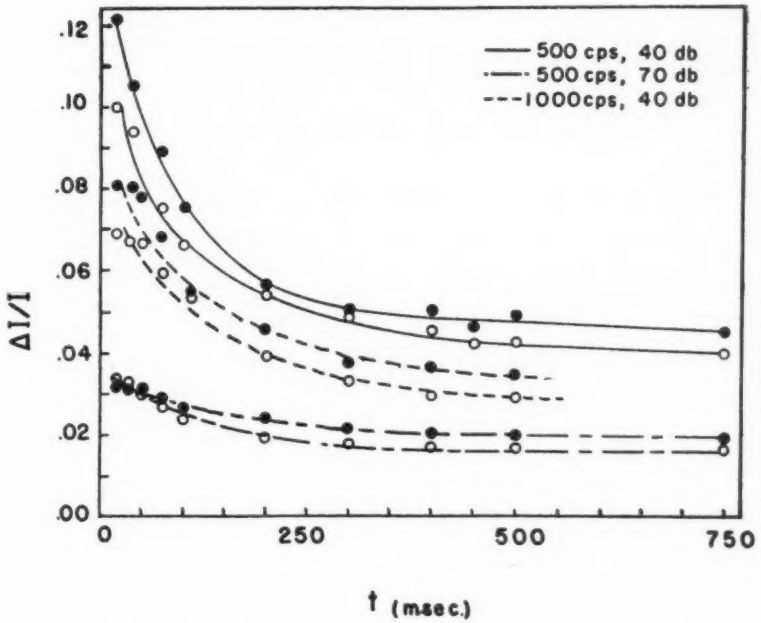

FIG. 2. Differential sensitivity to intensity ($\Delta I/I$) as a function of the duration of the comparison tone.

The three groups of two functions each represent the three sets of conditions under which the functions were run. Closed circles are for the data of WRG, and the open circles for the data of GAM. The data are from Table I, and all measures of differential sensitivity are in terms of voltage (pressure) changes.

stant of 1.5. Its use would not change the ratio of the highest to the lowest.

It might be argued in relation to the presentation of these data that there were not enough *O*s used, and that the variability might be more or less than that demonstrated here. The experiment was intended, however, to investigate differences in sensitivity within one individual under different conditions, and not to attempt an extensive evaluation of differences between individuals. It was felt, therefore, that two highly trained *O*s would give more accurate and reliable data than several relatively naive *O*s, and the consistency of the data supports this contention. It will be noticed that there are differences in the curves of the two *O*s, but these differences are highly consistent from one curve to another, and thus are indicative of real differences in sensitivity between the two *O*s. An assumption of constant neural units takes into consideration this difference in sensi-

tivity between individuals, so that the neural unit whose activation is necessary for a judgment of a difference in stimulus intensity may be constant for any one *O*, but is not necessarily constant from one *O* to another. This fact may be due to a difference in neural sensitivity, or to a difference in the number of elements constituting one neural unit.

Discussion

An attempt to determine from the psychological data the nature of the neural integrative process necessitates a mathematical and further graphical analysis. In any analysis of this sort, two approaches can be made. A rational equation can be assumed with which to start, and the adequacy of the mathematical hypothesis may be tested; or one may attempt to determine only the empirical relationship which exists, with no hypothesis in mind. Which of the two approaches is used depends partly on the availability of assumptions, and the two methods are usually used concurrently to a great extent. As long as there are rational equations which may fit the data, that approach is preferable, but when there are no longer any assumptions to be tested, then the purely empirical approach becomes necessary. The following discussion is a combination of the two techniques. First, the known hypotheses are tested, then an empirical statement of remaining possible explanations of the data is made.

Hypothesis 1. The integration is linear, and the quantity $I \times t$ will remain constant. This is a statement of the Roscoe-Bunsen law that

$$I \times t = k.$$

Thus, as time (the independent variable) is increased, intensity (the dependent variable) will be decreased by a proportionate amount. Another way of stating this relationship, and one which makes it easier to test graphically, is that

$$t = k/I.$$

Then if the reciprocal of I is plotted as a function of t in linear units, the resultant curve will be a straight line, the slope of which is determined by the constant k.

It is, however, unnecessary to plot the data in this manner to determine the adequacy of this hypothesis of linear integration, since we already know that the integration is not linear. There is going on with the integration process another process which we may call adaptation, which is such that, with a constant increase in stimulus quantity (either time or intensity, both being essentially stimulus

quantities), there is not an equivalent increase in excitation of the nervous system; rather as the stimulus value ($I \times t$) increases by equal steps, the excitation value increases by steadily diminishing steps, in accordance with the Weber function.

If we assume a constant number of elements to be excited (a reasonable assumption in view of the structure of the nervous system), a constant increase in stimulus quantity results in the excitation of a proportion of the elements still available in the nervous system for excitation. The number available will be large if the number already excited is small, and conversely, if the number excited is large, then the number available for excitation will be small. What proprotion of the available elements will be excited by any constant increase in the stimulus quantity is determined by the constants of the nervous system, and the greater the proportion excited with any given stimulus, the sooner will the increment in excitation approach zero.

If the number of fibers available for excitation (A) is inversely proportional to the stimulus quantity (I), and the increment in stimulus quantity necessary to produce a constant increment in neural excitation (ΔI) is inversely proportional to the number of elements available (A), then ΔI will vary directly with I, i.e., the increment of stimulus necessary for a constant increment of excitation will be proportional to the stimulus quantity. This is essentially a statement of a logarithmic relation between excitation and the stimulus quantity, which in this case is time, and thus leads us to the second hypothesis.

Hypothesis 2. The integration is logarithmic, and the quantity I log t will remain constant. Stated in mathematical form, this becomes

$$I \log t = k.$$

Thus, as the logarithm of time is increased, intensity will be decreased by a proportionate amount. Stated in a form more applicable to graphical treatment,

$$\log t = k/I.$$

This hypothesis has been tested in Fig. 3, the reciprocal of I being plotted as a function of the logarithm of t. In the actual plotting the reciprocal of I becomes $I/\Delta I$, since no actual values of ΔI were taken independently of I. This merely has the function of multiplying all the values by a constant, and thus does not detract from the ability of the curves to test the hypothesis.

It can be seen that over the center portion of the total range of durations, the curves approximate straight lines fairly closely. Both the upper and lower portions of the curves, however, tend to have a

slope which is less than that of the center part, and the curves resemble the cumulative normal ogive.

Crozier has predicted this phenomenon on the assumption that the thresholds of neurons are distributed in a normal fashion, according to the normal distribution. The reciprocal of I, as in this case, is a measure of accumulated excitation, and, as such, the curves should be cumulative normal curves.

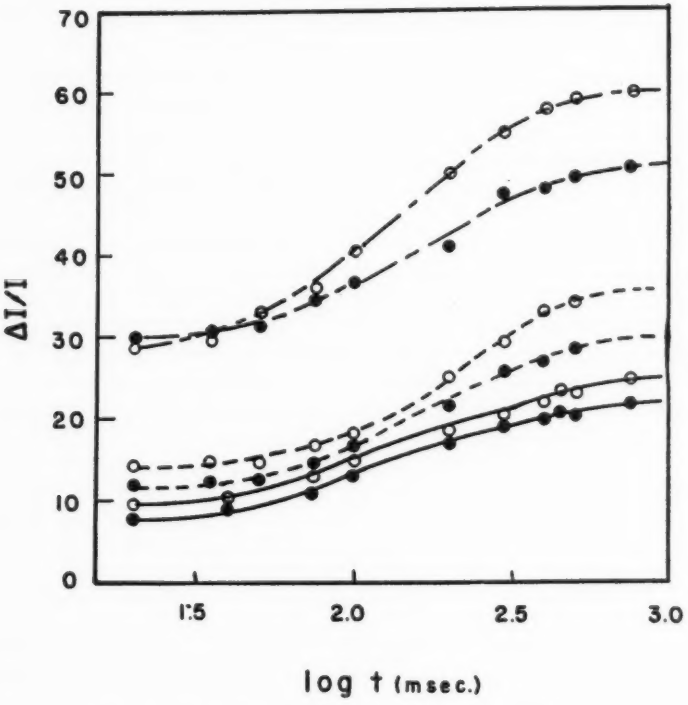

FIG. 3. The reciprocal of $\Delta I/I$ as a measure of sensitivity.

The reciprocals of the data of Table I are plotted as a function of log t to determine the linearity of the relationship ($I \log t = k$).

Hypothesis 3. The integration is logarithmic, but since the thresholds of the neurons are distributed according to the normal distribution, the integration measure should be the cumulative normal curve. Mathematically this becomes

$$1/\Delta I = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-\log t^2}{2\sigma^2}},$$

when log t is a deviation from the mean of log t, and σ is in terms of log t. This hypothesis can best be tested by finding some means of putting the ordinate in terms of percentages, and then plotting the curves on a probability grid, on which they should be straight lines if the curves are the cumulative normal ogive. This was done by plotting the ordinate as a percentage of the maximum minus the minimum value for each curve. The data are plotted in Fig. 4 this

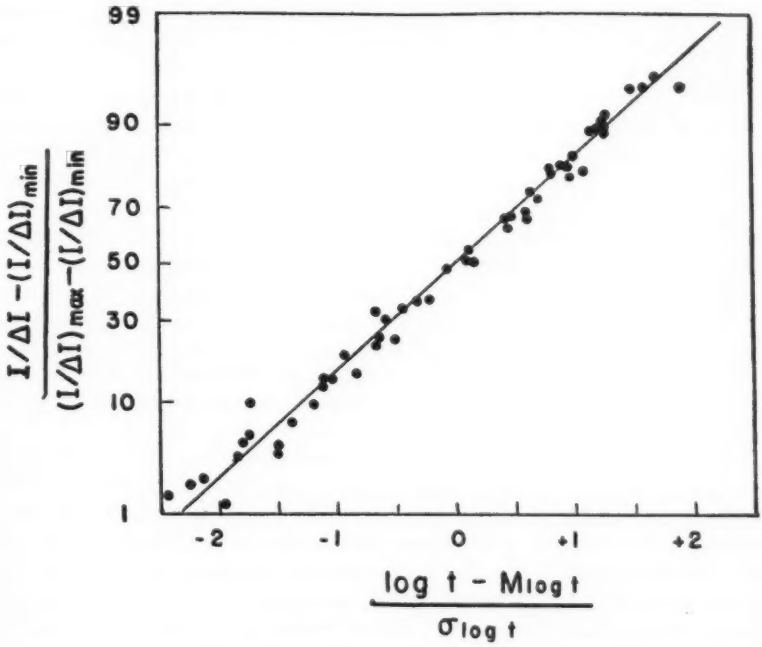

FIG. 4. Sensitivity as a normal probability function.

The curves of Fig. 3 are plotted on probability paper to determine the adequacy of the assumption that they are normal ogives. The ordinate is obtained by plotting percentage between maximum and minimum. The abscissa values are equated for mean and slope by plotting standard scores rather than raw logarithmic scores. See text for discussion.

way. Before plotting the data, however, the curves were equated so that they would all fall on the same line. The means and standard deviations of all the curves were equated so that the slopes and midpoints of all the curves would be the same. The abscissa values are thus standard scores. This is nothing more than multiplying each curve by a constant, and subtracting from each curve a constant. Doing this, however, makes it possible to state the theoretical

curve upon which all the points should fall if they are all perfect ogives. The curve shown with the plotted data of Fig. 4 is this theoretical curve, and it can be seen that the hypothesis is adequately substantiated.

Crozier has shown his hypothesis to be quite adequate in the field of vision, but there are differences and difficulties in the field of audition which make it dubious whether this assumption can adequately explain the form of the curves presented here. In audition there are many steps between the external stimulus and the nervous system, most of them, if not all, mechanical in nature. Each of these steps attenuates the stimulus to some extent. It may be that the attenuation over any range as small as that necessary for the determination of a differential threshold will be essentially linear, and thus may be disregarded, but there still remains another difficulty.

The curves presented here (Fig. 3) are normal curves only if one accepts the addition of a constant to the ordinate values (the reciprocal of ΔI). If these curves were actually representative of an integration process such as that proposed by Crozier, then the functions should approach zero much more rapidly than they do.

If we reject the only rational hypothesis which satisfies the data, then we are left in the position of having to take the data as empirically given, and having to attempt some explanation of why the curves do what they do. We find that there are possible two such explanations.

1. It may be that the auditory function, unlike the visual function, drops rapidly at some point lower than that which we were able to measure. This assumption is dependent on the further assumption that there are in reality two thresholds, rather than one, which the stimulus must overcome. The usually accepted threshold is the neural threshold. The other may be a mechanical threshold, due to the mechanical interference which a stimulus must overcome in order finally to reach the fibers of the eighth nerve. It was stated above that the increment in the stimulus rose to maximum amplitude in 10 msec. If there is a mechanical threshold, then the shorter tones would have an advantage, since the increased intensity which is necessary for the shorter tones to be heard as increments will overcome that threshold more quickly than will the longer tones, where a lower intensity is required. This relationship would have such an effect on the stimulus actually presented to the neurons that the shorter tones would produce a stimulus with a steeper wave front than would the longer tones. Stevens and Davis (**10**) have presented evidence showing that the more steeply a tone rises to its maximum intensity, the louder the tone appears. Fletcher (**4**) has stated that frictional forces may be the controlling factors for such small openings as the

round and oval windows. Further than this, both *O*s expressed the opinion that the shorter tones were easier to discriminate, that they showed change more definitely and had a more abrupt onset. This impression fits in quite well with the assumption that the shorter tones have a more abrupt onset than the longer tones, due to a mechanical threshold.

If this argument is valid, then the ear effectively adds a constant to the curve and is itself responsible for the fact that the curves presented do not approach more rapidly to zero. The data would not then verify Crozier's hypothesis of normal distribution of thresholds, since the bending of the lower portion of the curve would be due to a change in stimulus caused by the structure of the ear itself. On the other hand, the functions do not disprove this hypothesis for audition, but show merely that the hypothesis cannot adequately be tested under present conditions.

2. The other possible explanation of the bending of the lower portion of the curves more rapidly than seems necessary is that the external stimulus itself is effectively different for the shorter than for the longer tones. Sharply tuned filters, such as those used in this experiment, effectively cut out most of the transients which occur when a tone is turned on or off, but not entirely. It may be that with the increased intensity necessary to make the shorter tones heard, some of the transients which had been below the neural threshold are now above it, so that they are heard as part of the stimulus change, whereas they were not heard when the duration of the tone was longer, and thus the intensity less. Thus, these transients which are heard with the shorter tones will make the tone seem louder, and will also make the onset of the tone seem more abrupt, since they occur with the onset of the tone. This fact would also explain why the *O*s felt felt that the shorter tones were more abrupt in onset than were the longer tones. If this latter explanation gets at the real cause for the bending of the lower part of the curve, then the lower portion of each curve is not an adequate portrayal of the integrative process, but is rather a measure of stimulus deficiency. When the tone was checked on the oscilloscope, however, no transients were visible.

It is of interest to note that this work does not agree with Békésy's (1). As stated above, he found a linear relationship between the logarithm of time and intensity in decibels. The data here were plotted to determine whether that relationship holds for the range over which he worked (10–100 msec.), and it was found that it holds only very roughly. The curves tend to drop rather rapidly above 50 msec. The curve, however, is nearly linear if intensity is plotted in volts, rather than in decibels.

Summary

In order to show the relationship between the duration of the comparison tone and the intensity necessary to excite one additional neural unit, i.e., to produce the judgment of one j.n.d. in loudness, three functions were obtained with each of two *O*s. Each function had a different frequency and sensation level of loudness as constant parameters. A ratio as high as three was found between the highest and the lowest ΔI ratio in any one function.

The reciprocal of ΔI was used as a measure of the sensitivity of the organism to intensitive changes, and two hypotheses were presented to explain the form of the sensitivity function, both of which were rejected as being inconsistent with the obtained data. A third hypothesis was presented—the hypothesis of Crozier that the thresholds of the neurons are normally distributed, and that any measure of the sensitivity of the organism should be the normal cumulative ogive, when sensitivity is plotted as a function of the logarithm of time. Although the data seemed to substantiate this theory, the theory is rejected since the lower portions of the sensitivity curves do not approach zero as an asymptote, even though such an approach would be necessary if the curves were truly normal ogives.

Two possible explanations of the too rapid bending of the lower portions of the curves are given: (1) there may be a mechanical as well as a neural threshold which the stimulus must overcome, and which would make the wave front of the stimulus exciting the neurons different for the short and for the longer tones, or (2) transients in the tone which may be below the neural threshold for the longer tones (with a smaller amplitude) will come above the threshold for the shorter tones (with an increased amplitude).

The results presented here do not confirm the previous work of Békésy.

(Manuscript received June 1, 1944)

Bibliography

1. Békésy, G. v. Zur Theorie des Hörens. Uber die eben merkbare Amplituden- und Frequenzänderung eines Tones. Die Theorie der Schwebungen. *Physik. Z.*, 1929, **30**, 721–745.
2. Békésy, G. v. Uber das Fechnersche Gesetz und seine Bedutung für die Theorie der akustichen Beobachtungsfehler und die Theorie des Hörens. *Ann. Physik*, 1930, **7**, 329–359.
3. Crozier, W. J. The theory of the visual threshold. I. Time and intensity. *Proc. nat. Acad. Sci.*, 1940, **26**, 54–60.
4. Fletcher, H. *Speech and hearing*. New York: D. Van Nostrand Co., 1929.
5. Hecht, S. Energy relations in vision. *In*: Klüver, H. (Ed.), *Visual mechanisms*. Lancaster, Pa.: Jacques Cattell Press, 1942.
6. Lifshitz, S. Apparent duration of sound perception and musical optimum reverberation. *J. acoust. Soc. Amer.*, 1936, **7**, 213–221.

7. MILLER, G. A., & GARNER, W. R. The effect of random presentation on the psychometric function. *Amer. J. Psychol.* (*In press.*)
8. MORGAN, C. T. *Physiological psychology.* New York: McGraw-Hill, 1943.
9. STEVENS, S. S., & DAVIS, H. Psychophysiological acoustics: pitch and loudness. *J. acous. Soc. Amer.*, 1936, **8**, 1–13.
10. STEVENS, S. S., & DAVIS, H. *Hearing: its psychology and physiology.* New York: John Wiley, 1938.
11. STEVENS, S. S., & GERBRANDS, R. A twin-oscillator for auditory research. *Amer. J. Psychol.*, 1937, **49**, 112–115.
12. STEVENS, S. S., MORGAN, C. T., & VOLKMANN, J. Theory of the neural quantum in the discrimination of loudness and pitch. *Amer. J. Psychol.*, 1941, **54**, 315–335.
13. WALD, G. Area and visual threshold. *J. gen. Physiol.*, 1938, **21**, 269–287.

THE RELATION BETWEEN THE FOVEAL INTENSITY THRESHOLD AND LENGTH OF AN ILLUMINATED SLIT

BY ROBERT H. BROWN AND JORMA I. NIVEN[1]

Clark University

Three recent papers have been concerned with the relation of size of stimulus and intensity in the human eye. In the first, by Graham, Brown, and Mote (**5**), an hypothesis of the area-intensity relation has been developed and experimental data on the intensity threshold as a function of the radius of a white circular stimulating area have been presented for the fovea and periphery. In the second, by Graham and Bartlett (**3**), additional data have been obtained with red and violet light and the hypothesis has been extended in terms of certain photochemical considerations. In the third, by Graham and Bartlett (**4**), the hypothesis has been further developed to apply to foveal intensity discrimination thresholds. The present paper extends the analysis to a special case of the function describing the relation between the intensity threshold and radius of a circular stimulus area.

With the exception of some isolated observations by Abney (**1**), analysis of the area-intensity function has been restricted to the general case where the experimenter varies two dimensions of the stimulus surface simultaneously (generally the square of the radius of a circular area). As a special case it is pertinent to study the intensity of light required for threshold in the human fovea as a function of variation in one dimension of the retinal image. In addition, where the constant dimension of the retinal image is such that it approximates the diameter of a foveal cone, the function obtained indicates the nature of spatial summative effects in the activity of a single row of stimulated cones.

In our experiment we have attempted to approximate such a situation. Intensity thresholds have been determined for a vertical slit illuminated by light of variable length but of constant width. The *geometric* retinal image approximates in width the diameter of a foveal cone. Although the *actual* retinal image, when diffraction at the pupil and dispersion in the optic media are taken into account, must have been much wider than the cone diameter, results of a control experiment indicate that only the central portion of the light

[1] Division of Research, Graduate School of Business Administration, Harvard University.

distribution in the retinal image activated receptors and that (as an approximation) only a single row of stimulated cones determined the results of our experiment proper. In the control experiment we have decreased the width of the stimulus still further and obtained essentially the same function as for the wider stimulus.

To avoid the possibility of the extraneous effects of a variable critical duration, we have followed the procedure of earlier experimenters (**3, 4**), and used flashes of light of a constant duration less than the critical duration for our largest area (**7**). In order to be able more adequately to state our results as a special case of the relation between intensity threshold and radius of a circular area, we have repeated with the same apparatus, procedure, and *S*s as for the slit, that part of Graham, Brown, and Mote's experiment involving the fovea.

In an experiment involving a rectangular, as opposed to a circular, stimulus, it is desirable to have some measure of the effects of astigmatism. In another control experiment we have presented the illuminated slit rotated 90° so that it appeared to the *S* as a horizontal line.

Method

Three *S*s[2] served in the experiment proper. We obtained additional readings from two *S*s (ourselves) in one control experiment involving a 90° rotation of the illuminated slit from the vertical to the horizontal position and in a second control experiment in which we presented a narrower vertical slit than that used in the experiment proper. All results are for the left eye, fovea, and natural pupil (constant in size for each threshold determination under our adaptation and exposure conditions).

Each experimental session lasted about 1 hr. 10 min. We controlled adaptation conditions by the procedure of earlier studies (**3, 5**). Following a preliminary dark-adaptation of 15 min. at the beginning of a session, we determined the intensity thresholds by a modified method of limits for each of nine stimulus areas. Prior to two threshold determinations for a given stimulus area, the *S* observed a light-adaptation screen for 15 sec., and then dark-adapted for 105 sec. After two min. of successive light- and dark-adaptation, the *S* fixated the black center of the dimly illuminated foveal-fixation screen at repetitive commands of the *E*. Two ascending readings were made in steps of increasing brightness of approximately 0.07 *log I* unit from an intensity well below threshold. The *E* then repeated the process in making two more determinations for another stimulus area. All paired determinations were made within a three min. period, and approximately 15 sec. elapsed between each flash.

We systematically varied the order in which thresholds were determined with respect to both size and shape of stimulus. For the first four days the order was as follows:

	Shape of stimulus	Variation of size of stimulus
(*a*)	Circular	Large to small areas
(*b*)	Vertical slit	Large to small areas
(*c*)	Vertical slit	Small to large areas
(*d*)	Circular	Small to large areas

For the next four days the order was *dcba*. We devoted four experimental sessions in the middle of the experiment proper to the control experiment involving 90° rotation of the slit stimulus. During these four series the slit appeared in the horizontal position rather than the vertical

[2] We are indebted to Dr. Harry J. Older, our third *S*, for many hours of careful observations in the course of this experiment.

position as in earlier and later sessions. The *E* followed a *bccb* order in this first control experiment. The experiment proper concluded with eight more series of readings for each *S* in the order: *abcddcba*. In the second control experiment in which we presented a rectangular stimulus of markedly smaller width than that used in the experiment proper and the first control experiment, the order of experimental sessions was *bccbbccb*.

Thus, means based on 16 determinations for each of three *S*s and for each of nine stimulus areas are available in comparing the effect on the intensity threshold of varying the radius of a circular stimulus with the effect of varying the length of a vertical slit of narrow width. The eight threshold measurements (with each stimulus area) for the horizontal slit serve in indicating the effects of astigmatism on the relation obtained in the experiment proper. Finally, the 16 threshold determinations for each stimulus area of the very narrow vertical slit are useful in indicating the effects of a decrease in slit width on the same function.

The apparatus we used involves essentially the following pieces: (1) an optical system for presenting a stimulus of uniform light distribution and variable shape, area, and intensity; (2) a foveal fixation screen; and (3) a light-adaptation box. The optical system comprises a lamp, neutral-tint filters and wedge for control of intensity, a camera shutter and phonograph motor and record for restricting the duration of exposure, and a metal holder. Metal slides with circular holes of various diameters cut in them fit snugly into the holder next to an opal-glass screen and restrict the area of the stimulus. For some determinations we set in the holder an exposed photographic plate prepared so that the stimulus is an illuminated slit.

Fig. 1 illustrates schematically the arrangement of the optical system. Light from a 1000 w.

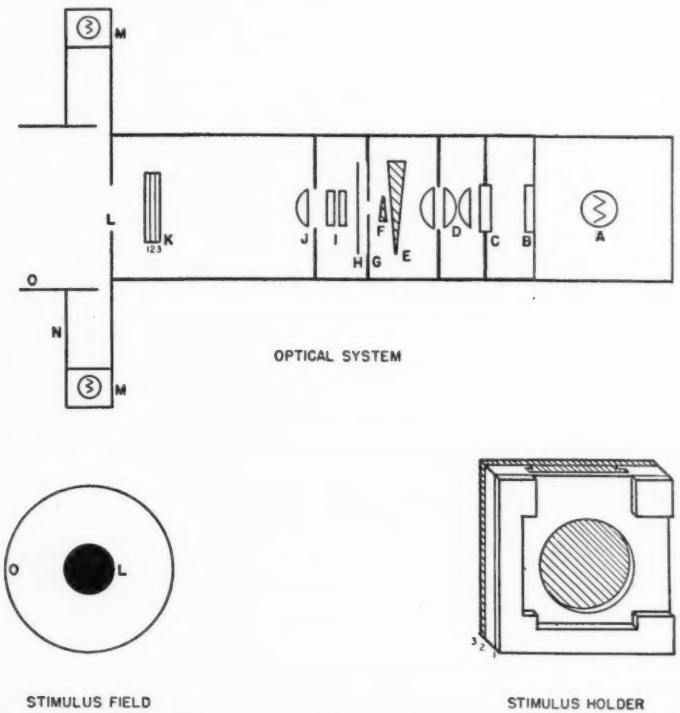

FIG. 1. Schematic diagram of optical system viewed from above, stimulus configuration fixated by *S*, and stimulus holder (*K* in diagram of optical system).

Mazda projection lamp (*A*), running on 110 v. D.C., passes through a calibrated Wratten neutral-tint wedge (*E*) with a range of 1 to 100 and its associated balancing wedge (*F*) and is focussed by means of three lenses (*D*) on a narrow slit of two beveled and ground edges 2.54 mm. apart. This slit (*G*) is used in restricting the size of beam near our exposure device.

The shutters interposed in the light beam between the lamp and the lenses protect the wedge and filters. The manually operated shutter (*B*) is an asbestos-covered wooden slide which is raised during a threshold determination to uncover the opening in the light-tight box surrounding the lamp. The camera shutter (*C*) is used in conjunction with a synchronized phonograph motor and record (*H*) which revolves parallel and close to the slit. This second shutter is a selective device enabling the *E* to present a single flash when desired.

The record has a radial slot cut from its periphery. Since the disk revolves at 84.0 r.p.m. and has an open sector of 4.23°, there is a flash with a duration of 10.7 msec. every time the sector, 5″ from center of record, passes the slit when both shutters are open. The image of the filaments of the lamp at the slit is appreciably less than the width of the slit, and the full intensity of the flash is present for at least 6.1 msec. The *E* presents one flash at a time by opening the camera shutter for 1/2 sec. when the open sector of the record passes a dim beam of light placed before the slit by 270° of the record's rotation.

The intensity of the stimulus flash is controlled not only by the wedge, but also by neutral-tint Wratten filters. After passing through the filters and their holder (*I*), the diverging flash of light continues through the collimating lens (*J*) and in parallel rays to the opal-glass stimulus surface (*K-3*). Between the opal glass and the *S* the *E* places a metal plate (*K-2*), which restricts the stimulus area, and a specially prepared photographic plate (*K-1*) which still further restricts the stimulus surface in some experiments to a narrow illuminated slit. Circular holes, accurately centered, are cut in the metal plates used to restrict the stimulus area.

The photographic plates which delimit the stimulus surface to a slit have been prepared by exposing a spectroscopic plate of high resolving power to a large white cardboard on which is drawn a line in India ink of 10 times the desired width of the slit. By this procedure we reduced the variation in width of the inked line 10 times in the photographed image. We have calibrated the two plates used in this study by means of a microscope and ocular eye-piece. In each case the width of the unexposed slit is sufficiently constant for our purposes throughout the length of the 4 × 5 in. plate. Forty measurements, equally distributed along the full length of the slit, yield a mean of 0.882 mm. and a standard deviation for the distribution of .005 mm. for one plate The mean of 40 measurements is 0.182 mm. and the standard deviation .004 mm. for a second plate. The first stimulus slit, used in the experiment proper, subtends in width a visual angle of 0.63′ at the eye. The second, used in the second control experiment, subtends an angle of 0.13′.

The photographic plate is fitted snugly in a position within 1/16 in. of the metal plate determining the area. The metal plate, 1/16 in. thick, in turn fits snugly into the stimulus holder in a position such that it is 1/16 in. from the opal side of the stimulus surface. The stimulus holder into which the photographic and metal plates fit is represented schematically in Fig. 1. It consists of three main sections. Section 1 is a piece of metal cut so that the 4 × 5 in. photographic plate can be inserted into the holding device either vertically or horizontally with respect to its long axis. Section 2 consists of two metal sheets fastened together, in one of which is cut a circular opening, 80 mm. in diameter. The second piece is U-shaped and is slotted so that the metal plates determining the circular areas may be slid firmly into position before the circular opening. Both the photographic and metal plates are thus readily placed into precentered positions. Section 3 of the stimulus holder is the opal-glass screen forming the stimulus surface.

The foveal fixation screen is arranged as follows. Parallel to, and 92 mm. in front of, the opal-glass stimulus surface, there is a large piece of white cardboard in the center of which there is a circular opening (*L*), 121 mm. in diameter. This cardboard is illuminated by four 3.8 v. flashlight bulbs, each of which is run on 3.5 v. from a storage battery. The lamps are fastened in chalk boxes (*M*), which have milk-glass fronts shielded from the eye of the *S* by another cardboard with a circular opening 417 mm. in diameter (*N*). A black cardboard cylinder (*O*) inserted in this latter opening prevents reflection of light from the walls, floor, and ceiling of the room. Under these conditions the brightness of our foveal fixation screen is 0.01 ml.

The stimulus configuration seen by the *S* is indicated in Fig. 1. It may be noted that in terms of the visual angle subtended at the eye the stimulus configuration is identical with that used in earlier studies, although in the present experiment the *S* is seated much farther from the stimulus area.

The light-adaptation box involves an opal-glass surface illuminated by four 25 w. frosted bulbs operated at 110 v. D.C. The light-adaptation screen, 274 × 247 mm., has a brightness of 330 ml. During the experiment it is placed 150 cm. from the *S*'s left eye and on a level with, and 8° to the right of, the *S*'s line of sight when fixating the stimulus area.

During experimentation the *S* views the stimulus field with his head firmly placed in a stereoscopic hood which has had its lenses removed. Since all observations are for the left eye, the right side of the hood is covered with black paper. The hood is placed 486 cm. from the stimulus field in a position such that the *S*'s left eye is centered in the extended optical path.

Results

Our results for the foveal intensity threshold as determined by the radius of the white circular area are presented in Table I. It

TABLE I

Intensity Thresholds and Radius of Circular Area

Radius of stimulus in minutes	Logarithm of threshold intensity in millilamberts				
	RHB	JIN	HJO	Mean	Calculated from equation (2)
0.693	0.932	0.862	1.058	0.951	0.982
1.00	0.447	0.466	0.564	0.492	0.540
1.44	0.133	0.174	0.239	0.182	0.173
2.24	−0.166	−0.177	−0.076	−0.140	−0.190
3.96	−0.462	−0.487	−0.447	−0.465	−0.553
5.94	−0.720	−0.708	−0.736	−0.721	−0.758
8.59	−0.874	−0.892	−0.914	−0.893	−0.910
14.4	−1.042	−1.118	−1.107	−1.089	−1.079
25.5	−1.272	−1.348	−1.392	−1.337	−1.224

may be noted that, as the radius (measured in minutes of visual angle subtended at the eye) increases from less than a minute to about half-a-degree, the logarithm of the threshold intensity in millilamberts decreases. The rate of decrease is less with increasing radius, and for the larger areas the threshold approaches an asymptotic value. In this respect the function is similar to that obtained in earlier studies. For convenience of comparison, Table I presents in the fourth column a mean of the average values for three *S*s and in the fifth column a theoretical value calculated from an equation presented in the next section. Each entry in Table I (and Table II) for an individual *S* represents the mean of 16 separate threshold determinations.

Table II presents our results for the foveal intensity threshold as a function of slit length. Here the stimulus is a vertical slit illuminated by white light, the length of which is systematically varied during the experiment while the width is constant and of the order of magnitude of a cone. As for the circular area, the intensity threshold decreases as the stimulus size increases. The rate with which the

TABLE II

INTENSITY THRESHOLDS AND LENGTH OF SLIT

The illuminated vertical slit of this experiment subtends in width a visual angle of 0.63′.

Length of slit in minutes	Logarithm of threshold intensity in millilamberts				
	RHB	JIN	HJO	Mean	Calculated from equation (5)
2.00	1.071	0.923	1.091	1.028	1.003
2.88	0.804	0.764	0.881	0.816	0.802
4.48	0.633	0.601	0.689	0.641	0.612
7.92	0.476	0.436	0.505	0.472	0.417
11.88	0.318	0.307	0.369	0.331	0.306
17.18	0.206	0.238	0.257	0.234	0.219
28.8	0.084	0.147	0.117	0.116	0.118
51.0	−0.007	−0.065	−0.080	−0.051	0.021

threshold decreases when only one dimension is varied is much less, however, than in the former case where the variation is in two dimensions.

The relative variation of threshold intensity with radius of a circular area and with slit length is evident in Fig. 2, where the open

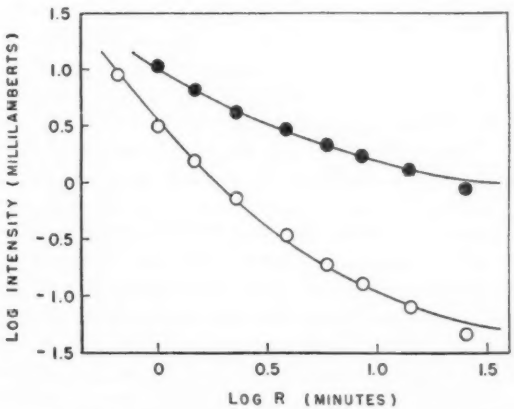

FIG. 2. Foveal intensity threshold as a function of radius of circular area (lower curve) and length of slit (upper curve).

circles and lower curve represent the thresholds for the circular area, the closed circles and upper curve the thresholds for the slit. Each point in the figure represents 48 determinations in all or 16 for each S. The curves are theoretical and are calculated from equations (2) and (5). For convenience in later discussion we have plotted the loga-

rithm of the threshold intensity in millilamberts against the logarithm of R, where R is the radius of the circular area or one-half the length of the slit. The drop of the final experimental point below a smooth curve is evident for both stimulus surfaces. Measurements made with red light in an earlier study (**3**) indicate that this drop results from the contribution of rods stimulated by the largest stimulus area.

The decrease of threshold with increase of size of stimulus is indicative of spatial summation and convergence of excitation from outlying cones upon a common neural center. The threshold decreases at a much slower rate and approaches the asymptotic limiting value more gradually when one dimension (length of slit) is varied than when two dimensions (radius of circular stimulus) are increased. While the summative effect is present in our slit experiment, then, its magnitude is much less than in the more general case where stimulus area is varied.

Observations made by our *S*s are of some interest in this connection. An *S* reports presence of light from the longer slits before he can resolve the direction of the slit. Excitation sufficient for the threshold effect is inadequate for resolution. As the E gradually increases, in constant logarithmic steps, the intensity of flashes appearing in the center of the fixated stimulus field, the *S* observes first a blurred blob of light and later (at greater intensities) a clearly outlined and resolvable slit. The transition from excitation adequate for a threshold response to that required for resolution is much sharper and occurs in fewer intensity increments for the slit than for the circular area and for the larger stimulus, whether slit or circular, than for the smaller one. These observations are in harmony with similar data based on the threshold response (**1**, **5**) and the optic nerve discharge (**2**, **6**). They serve to reëmphasize the spatial effects occurring in the vertebrate retina even when the stimulus is a narrow illuminated slit and the summation occurs largely in only one dimension.

The preceding observations also raise the question of the effects of astigmatism on the functions we are studying. With reference to the relation between threshold intensity and radius of circular area, presumably astigmatism is one of the factors determining the asymptotic limiting value of the threshold for larger areas, a constant which may vary in some degree from *S* to *S*. Apart from its effect on this constant, it is doubtful that astigmatism influences the function. In the case of threshold intensity and length of slit, however, the shape of the curve describing the function as well as its position relative to the intensity axis might be determined in part by astigmatic properties of the eye, since variation in size of stimulus occurs in only one direction.

In our first control experiment, we have presented the slit in a

horizontal position rather than the vertical position of the experiment proper. Table III presents results based on eight determinations for each of two *S*s. For convenience of comparison the thresholds reported earlier for the vertical slit are listed in the second and fourth columns. It may be observed that the threshold intensity is slightly, but consistently, higher for the horizontal slit than for the vertical slit. Thus, there is an average discrepancy of 0.03 log *I* unit for each of the two *S*s. The deviation between the two sets of readings is rather uniform for the various lengths of slit and represents a constant displacement of small magnitude along the log *I* axis of Fig. 3.

TABLE III

COMPARISON OF THRESHOLDS FOR HORIZONTAL AND VERTICAL SLITS

The illuminated slits of this experiment subtend in width a visual angle of 0.63′.

Length of slit in minutes	Logarithm of threshold intensity in millilamberts			
	RHB		JIN	
	Vertical	Horizontal	Vertical	Horizontal
2.00	1.071	1.140	0.923	1.100
2.88	0.804	0.785	0.764	0.725
4.48	0.633	0.643	0.601	0.548
7.92	0.476	0.490	0.436	0.453
11.88	0.318	0.370	0.307	0.403
17.18	0.206	0.228	0.238	0.240
28.8	0.084	0.145	0.147	0.100
51.0	−0.007	0.023	−0.065	0.025
Mean log. *I*	0.448	0.478	0.419	0.449

In Fig. 3 the logarithm of the threshold intensity in millilamberts has been plotted against the logarithm of half the length of the slit (*R*). The average thresholds for the vertical slit are indicated by the open circles for each of the two *S*s, while the closed circles represent corresponding values for the horizontal slit. It may be noted that there is little difference between the two sets of determinations and that the theoretical curve drawn through the experimental points fits either set equally well. We may conclude that astigmatism has had a negligible effect upon our results.

The semi-closed circles of Fig. 3 indicate the nature of our threshold determinations with the very narrow stimulus slit of the second control experiment. This vertical slit subtends in width a visual angle of 0.13′ rather than 0.63′ as for the other determinations. It is evident that decreasing the stimulus width does not decrease the summative effect already noted. The rate with which log *I* changes

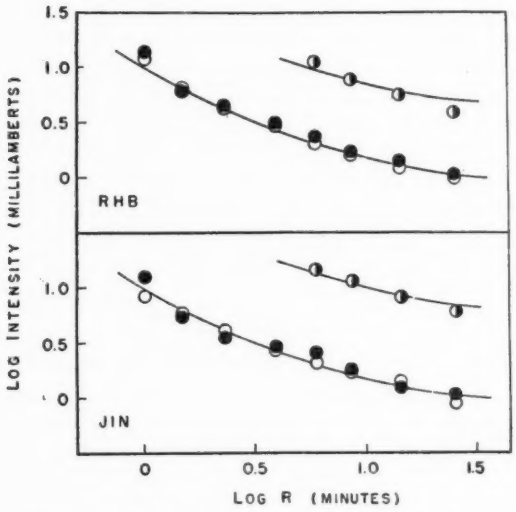

FIG. 3. Foveal intensity threshold as a function of slit length. Lower curve for each S represents the threshold for vertical (open circle) and horizontal (closed circle) slits subtending in width a visual angle of 0.63′. Upper curve (half circle) for each S represents the threshold intensity for vertical slit subtending an angle of 0.13′.

with respect to log R is at least as great as for the wider slit. We may reasonably infer from this that our original stimulus slit excites, by and large, a single row of cones, and that use of a more narrow slit results in less excitation of each cone in the row and therefore in approximately constant displacement upward along the log I axis.

Table IV presents the mean thresholds for each S as measured on

TABLE IV

COMPARISON OF THRESHOLDS FOR NARROW AND VERY NARROW SLITS

The vertical slits of this experiment subtend in width visual angles of 0.63′ and 0.13′.

Length of slit in minutes	Logarithm of threshold intensity in millilamberts			
	RHB		JIN	
	0.63′	0.13′	0.63′	0.13′
11.88	0.318	1.059	0.307	1.159
17.18	0.206	0.896	0.238	1.059
28.8	0.084	0.746	0.147	0.913
51.0	−0.007	0.591	−0.065	0.783
Mean log. I	0.150	0.823	0.157	0.978

16 occasions with the 0.13′ slit for comparison with corresponding values obtained with the wider slit.

Discussion

As the length of a narrow illuminated slit increases, the threshold decreases in intensity although at a rate less than where the diameter of a circular stimulus varies. In our experiment, the rate of change of log I with respect to log R is independent of astigmatic effects and of further decrease in width of the already narrow slit. These and other observations reported in the preceding section may be readily interpreted quantitatively in terms of the notion of a spatial gradient of excitation formulated by Graham (**3, 4, 5**).

With reference to an illuminated circle the assumption is made that each elemental area, $r\,dr\,d\theta$, contributes to the center in inverse proportion to a power, p, of its distance, r, from the center. Thus, for a threshold response, the constant excitatory effect, E, at the center is

$$E = k_1 e \int_0^{2\pi} \int_0^R \frac{r\,dr\,d\theta}{r^p}, \tag{1}$$

where R is the radius of the stimulating circular area, e the constant intensity effect in each elemental area, and k_1 a constant of proportionality.

When we follow a tentative suggestion by Graham and Bartlett (**4**), based on their results for the foveal intensity discrimination threshold, and substitute a value of unity for p and $k_2(\log I/I_0)^2$ for e as approximations, equation (1) may be solved for

$$\log I = \log I_0 + CR^{-\frac{1}{2}}, \tag{2}$$

where

$$C = (E/2\pi k_1 k_2)^{\frac{1}{2}}. \tag{3}$$

Here, I_0 is the threshold intensity of a single cone. Its use in equation (2) indicates that the threshold intensity for very large areas is determined approximately by that for the single cone. As the illuminated circular stimulus increases in area, the threshold is ultimately limited by the minimal intensity required to excite each cone. In our figures the asymptote of the curve on the log I axis represents log I_0. We have computed by the method of least squares a value of -1.66 for log I_0 and of 2.20 for C from our average data on the circular stimulus area. The curve for the circular stimulus of Fig. 2 represents the values of log I calculated from equation (2) with these constants and indicated in Table I. The theoretical fit

for the circular data is adequate, although we disregard, by our use of mean threshold intensities, the individual variation in log I_0. The chief discrepancy between experimental point and theoretical curve occurs with the largest area and is a function of rod activity, not controlled in this experiment with white, rather than red, light.

This analysis may be extended without much modification to the special case of threshold intensity as a function of the length of a slit approximating in its constant width the magnitude of a cone. When the slit of Fig. 2 increases in length, outlying cones contribute by increasing subliminal summation to the excitatory effect at the center, as indicated by the decrease in log I. Although, undoubtedly, it would be helpful here to consider the limits of the receptive unit, the function may be satisfactorily and more simply expressed in this approximate form:

$$E = 2k_1 e \int_{R_0}^{R} \frac{dr}{r^p}, \tag{4}$$

where R, one-half the length of the slit, and R_0 (in place of an insolvable 0) indicate the limits within which each elemental length, dr, contributes $k_1 e/r^p$ to the excitatory effect, dE, at the center. When p and e are assigned the same values as for the circular area, this expression may be solved for

$$\log I = \log I_0 + C' (\log R/R_0)^{\frac{1}{2}}, \tag{5}$$

where

$$C' = (E/4.6k_1k_2)^{\frac{1}{2}}. \tag{6}$$

The value of log I_0 (-1.66) is given immediately by the experiment on the circular area. That for C' is easily determined from the C of that experiment and from equations (3) and (6). This calculation yields a value of 2.57 for C'. Using these values for log I_0 and C', we have computed by the method of least squares a value of 0.117′ for R_0 from substitution of mean slit threshold intensities and their corresponding R values in equation (5). The small value of R_0 indicates a lower limit to the general inverse proportionality between threshold effect and distance from center in a very short illuminated slit, the length of which is markedly less than the diameter of a cone.

Equation (5), with the constants determined in this way, has been plotted as the upper curve of Fig. 2, denoting variation of threshold intensity with length of vertical slit. The theoretical values are also listed in Table II. It is evident that the equation adequately describes the mean data. The adequacy of fit is further indicated by the lower curves of Fig. 3. Here, the same theoretical curve describes the variation of slit threshold for each of two *S*s as well as it does the mean data of Fig. 2.

The effect of using a narrower slit (0.13′ of visual angle in width rather than 0.63′) is to increase the value of log I_0, but not change the other constants of equation (5). Thus, the upper curves of Fig. 3 represent the same equation as the lower ones but with values of −0.99 (RHB) and −0.84 (JIN) for log I_0, rather than −1.66 as for the wider slit and the circular area. We may infer that, over a wide range in variation of length of a narrow slit, each elemental length contributes in inverse proportion to its distance from the center. Use of a slit, the width of which is markedly less than the diameter of a cone, results in an increase in the threshold intensity of each elemental length, but does not modify the nature of its contribution to the center.

As the width of a narrow illuminated slit decreases, the threshold intensity (I_0) of each cone illuminated by the slit increases. Each activated cone continues to contribute to the minimal threshold effect at the neural center in inverse proportion to its distance from the center. This proportionality is independent of slit width when less than cone diameter. However, for very short slits, the proportionality is limited by activity within the receptive unit.

Summary

1. We have described a method of determining accurately for the human fovea intensity thresholds of narrow illuminated slits for comparison with similarly obtained thresholds of circular areas.

2. The threshold is high for short slits and decreases as the slit increases in length. The rate with which the threshold decreases is markedly less as a function of length of slit than as a function of diameter of illuminated circle.

3. Astigmatic effects which might appear in the experiment actually do not influence the decrease of threshold with increase of slit length. Further decrease in width of the narrow slit apparently operates to increase the threshold uniformly, irrespective of length of slit.

4. The results are interpreted quantitatively in terms of a spatial gradient of visual excitation.

(Manuscript received May 23, 1944)

References

1. Abney, W. *Researches in colour vision.* London: Longmans, Green, 1913. Pp. 418.
2. Adrian, E. D., & Matthews, R. The action of light on the eye: III. Interaction of retinal neurones. *J. Physiol.*, 1928, **65**, 273–298.
3. Graham, C. H., & Bartlett, N. R. The relation of size of stimulus and intensity in the human eye: II. Intensity thresholds for red and violet light. *J. exp. Psychol.*, 1939, **24**, 574–587.

4. GRAHAM, C. H., & BARTLETT, N. R. The relation of size of stimulus and intensity in the human eye: III. The influence of area on foveal intensity discrimination. *J. exp. Psychol.*, 1940, **27**, 149–159.
5. GRAHAM, C. H., BROWN, R. H., & MOTE, F. A., JR. The relation of size of stimulus and intensity in the human eye: I. Intensity thresholds for white light. *J. exp. Psychol.*, 1939, **24**, 555–573.
6. HARTLINE, H. K. The response of single optic nerve fibers of the vertebrate eye to illumination of the retina. *Amer. J. Physiol.*, 1938, **121**, 400–415.
7. KARN, H. W. Area and the intensity-time relation in the fovea. *J. gen. Psychol.*, 1936, **14**, 360–369.

THE GENERALIZATION OF EXTINCTION EFFECTS WITHIN A HABIT PATTERN

BY JOHN M. FELSINGER *

The Ohio State University

Recent studies have begun to tap the full implications of conditioning for behavior theory in general, and an expanding set of vigorous and promising behavior principles are being developed. As a result, the conditioned response can no longer be viewed as an unstable artifact inapplicable to complex behaviors outside the controlled laboratory situation. As long as interest in this phenomenon restricted itself to experiments upon the effect of variations of the conditioned and unconditioned stimuli upon the conditioned response, the application for behavior remained markedly limited. While these classical studies have been extremely important in our understanding of behavior in these strictly defined and controlled situations, unfortunately the life situation is rarely characterized by controlled conditions. Thus, critics have been prone to regard the conditioned response as a segment of behavior whose fragility and rigidity make it unapplicable to the fluid life situation. Such critics have tended to overlook the possibilities of stimulus and response equivalence characteristic of the conditioned response. The conventional symbol S—R, indicating a specific receptor-effector connection, united by a reinforcement, suggests this interpretation, obscuring the fact that every conditioning not only sets up a specific receptor-effector connection, but also mediates connections between a great number of receptor-effector processes. More simply, the response involved is elicitable not only by one specific stimulus, but by a class of similar stimuli, and, likewise, the specific stimulus tends to elicit not just one specific response, but one of a class of responses. This fact should tend to stimulate a new orientation in conditioning research. Instead of assaying the effect of historical conditions on the conditioned behavior, a more pertinent and applicable program would attempt to uncover the dynamic relation of the CR to varying environmental situations. This is essentially a problem in generalization of conditioned phenomena. Some work along this line is already available. Pavlov (4) himself first demonstrated the possibilities of such func-

* This study grew out of Professor F. C. Dockeray's seminar. The technique was proposed by Ralph H. Turner who entered the Army before the investigation could be undertaken.

tional relationships, and Hovland (2, 3), Ellson (1), Wickens (11, 12), Wenger (6), Razran (5), and especially Hull (4) have contributed much. Nevertheless, this aspect has barely been tapped.

The present experiment, while designed to investigate the generalization of extinction effects within a habit pattern, has raison d'être only insofar as it contributes to this larger picture of conditioning as a basic and broad behavior principle.

Specifically, our problems are these: (1) Do the difficulty or extinction effects of environmental variation experienced by one part of a habit pattern generalize to the rest of that pattern? (2) What quantitative relation exists between these generalization effects and the amount of environmental variation?

Pavlov (8) noted the generalization of extinction effects, and Hull (4) has recently suggested application of a simple negative growth function as its possible quantitative law. However, research in this subject has been concerned with the generalization of extinction effects along a single continuum—sensory or effector—and has been demonstrated in only a single conditioned response. But in life situations we rarely are concerned with a single conditioned response but rather with a number of them organized into a habit, and again, with not just one habit but with more or less complex habit patterns. Thus, the application of generalization of extinction effects to a habit pattern becomes of some practical importance.

Translated into experimental terms, we might set up a habit pattern involving two or more specific habits or conditioned responses, and then systematically vary the stimulus situation of the first, observing the effects upon the subsequent responses in the pattern. Thus, rats were trained in two visual discriminations which were presented in series requiring two correct discriminations before the reward was obtained. Visual discrimination I was then made more difficult by altering the positive stimulus so that it more and more resembled the negative stimulus. The effect of this procedure was noted on discrimination habit II, which remained unchanged in every respect.

Experimental Technique

The apparatus used was essentially that developed by Lashley. Two discrimination stands or screens, each with two square openings for stimulus cards, were used, one behind the other. The stimulus patterns were mounted on pieces of cardboard and placed in these openings. The negative stimulus card was fixed rigidly so that when the animal jumped against it, he fell into the net. The positive stimulus card fell back readily if jumped against.

Thirteen rats were first trained in a simple discrimination, the stimuli consisting of a black circle on a white background and a white circle on a black background. To induce jumping in this learning situation a light shock of constant strength was applied every 10 sec., following a 20-sec. orientation period. In most cases a 100 percent mastery of the discrimination was obtained. The criterion was 30 successive correct jumps.

Following this habit acquisition, the rats were trained in a second discrimination, the stimuli consisting of a horizontal and vertical black bar on a white background. This was a considerably more difficult habit than the first discrimination. Eighty percent correct discrimination on 30 successive trials was required as the criterion of learning.

The two habit discriminations were then combined with the apparatus containing the horizontal and vertical bar discrimination (hereafter referred to as habit I), placed before the apparatus containing the black and white circles (to be referred to as habit II). Thus, the animals were required to make two successful discriminations before reward. Then, on three consecutive days, 30 control discriminations (10 per day) were run with a close record kept of errors and time for each jump. Several rats seemed disturbed at first by this patterning of habits acquired singly, and required more than 40 trials to regain the required criterion. It is interesting that this disturbance in all cases affected only habit I. It is to be noted that under this procedure, habit II was in all cases overlearned by a minimum of 40 correct responses, and in some cases as much as 80 successful trials.

When the total habit pattern was well learned, the experimental runs were begun. These consisted of successive trials (until 10 successes had been made) under five experimental conditions, involving systematic alterations of the positive stimulus of habit I. On the first day of the experimental runs, the vertical bar was slanted toward the horizontal, forming a 60 degree angle instead of the regular 90 degree angle, making the discrimination of habit I theoretically more difficult. On successive days the positive bar was slanted more and more in four additional steps, 30, 15, 10 and 5 degrees, respectively. Throughout these stimulus changes in habit I, the stimulus of habit II remained unaltered and jumping conditions constant. The mean time and errors of each day's runs for both habits were recorded and compared with the mean time and errors of the control runs. This comparison is in terms of the *t*-function.

Our problem concerns the effects of this systematic variation of habit I upon habit II which has remained unaltered. Assuming that the level of difficulty or degree of stimulus variation encountered by habit I should generalize throughout the habit pattern, we would expect that there would be a proportional increase in both errors made and in time before jumping, not only in habit I but also in habit II.

The Data

The results fall into three categories: (1) those that present a totally positive reaction to the experimental conditions, that is, show generalization of extinction effects (five cases); (2) those cases that present both negative and positive experimental runs (six cases); (3) totally negative cases (two cases).

The records of rats Nos. 5 and 14 are illustrative of the first group. The data in Table I for rat No. 5 present a clear, positive case with both criteria of difficulty—time and errors—showing a substantial increase in habit I. The time in habit II reflects the disturbance of habit I by steadily increasing with each experimental variation of habit I.

The record of rat No. 14 (Table II) is an example of the dynamics involved in our problem. Here we see an initial disturbance under the first experimental conditions followed by a recovery of both habits in the second series. Habit I in the 15 degree and 10 degree series is sharply disturbed, which disturbance is reflected in comparable breakdowns of habit II. The 5 degree conditions, theoretically the most difficult, affect neither habit. The striking recovery of the 30 and 5 degree series under conditions supposedly more difficult than the preceding ones is both unexpected and unaccounted for. Obviously,

TABLE I

SUMMARY OF DATA OF RAT NO. 5 *

	Discrimination I				Discrimination II			
	Errors	Mean time	*t*	*P*	Errors	Mean time	*t*	*P*
Control runs.....	2	7.47			0	7.43		
Experimental runs								
60°.....	4	10.85	1.99	.05	0	10.3	2.05	.05
30°.....	5	9.73	1.40	.2	0	10.9	3.05	.01
15°.....	4	15.38	3.92	.001	0	16.1	5.08	.001
10°.....	5	21.86	6.90	.001	0	25.79	9.9	.001
5°.....	7	20.64	5.46	.001	0	29.7	9.29	.001

* The number of errors for control runs is the mean of three days' runs, composed of 30 correct discriminations, plus three times the number of errors shown. This is done to facilitate comparison with the experimental runs which are composed of 10 correct discriminations plus errors.

The *t*-score was obtained from time differences only, since error disruption was seldom significant.

a new factor has entered the field. This sudden variation, while not unusual in selective learning situations, is nevertheless of utmost significance for our study, for according to our hypothesis, not only should breakdowns in one part of a habit pattern be followed by breakdowns in other parts—as is demonstrated in the 60 and 10 degree experimental conditions—but also, recovery of that habit

TABLE II

SUMMARY OF DATA OF RAT NO. 14

	Discrimination I				Discrimination II			
	Errors	Mean time	*t*	*P*	Errors	Mean time	*t*	*P*
Control runs.....	3.3	9.15			0	7.66		
Experimental runs								
60°.....	3	13.46	2.34	.02	0	16.1	8.17	.001
30°.....	3	10.0	.53	.6	0	6.3	1.67	.1
15°.....	8	38.70	9.91	.001	0	12.1	3.39	.001
10°.....	6	20.0	3.79	.001	0	9.8	1.82	.01
5°.....	3	8.07	.63	.5	0	8.7	1.04	.3

from difficulty or inhibition should also be generalized to the same associated habit parts. This has occurred in our data, for not only has habit I suddenly ceased to be affected by our experimental variation (30 and 5 degree series), but what is important, the rest of the pattern (habit II) has likewise recovered. Since conditions of habit II have remained constant in all experimental runs, there is little to account for these changes except its organismic connection with habit I which is undergoing change.

We note that in none of our cases have the generalized effects of our gradual extinction of habit I been sufficient to produce errors in habit II. However, in all cases a significant disruption of habit I in terms of time has been followed by a significant increase in time in habit II. That the generalization of extinction effects should be sufficient to produce time increases but not errors is understandable when we consider that, first, extinction effects generalized or transmitted from habit to habit within a pattern would lose in intensity, and secondly, the amount of generalization effects would be governed by both the strength of the individual habits within the pattern as well as the strength of the relation between the habit units which bind them into a pattern. While the latter is more difficult to determine, we do know that in our animals habit II was considerably overlearned and was thus more highly resistant to inhibition effects.

While the six cases in category No. 2 contain negative series, the group as a whole presents a total of nine negative experimental series and 16 positive ones. Again, but with one exception, severe breakdown in errors in habit I is always followed by a significant breakdown in time in habit II. The record of rat No. 8 (Table III)

TABLE III

SUMMARY OF DATA OF RAT NO. 8

(30 degree series lost)

	Discrimination I				Discrimination II			
	Errors	Mean time	t	P	Errors	Mean time	t	P
Control runs.....	1.3	7.64			.6	6.87		
Experimental runs								
60°.....	2	7.41	.17	.9	0	9.00	2.40	.02
15°.....	14	7.16	.42	.7	0	9.5	2.11	.05
10°.....	3	4.92	2.1	.05	0	6.3	.67	.5
5°.....	24	*			0	11.18	3.85	.001

* See discussion.

is illustrative of the data presented by this group. This record contains two negative and two positive series. The initial stimulus alteration does not affect habit I, but habit II shows significant time increase for a negative series. The 15 degree variation clearly disrupts habit I, and habit II responds with a significant time increase. The 10 degree series provides an interesting run. Here we have a significant negative time difference—a decrease instead of an increase. Adhering to the derivations from our basic hypothesis, we might expect a significant decrease in time of habit II. The empirical results do not bear us out. Though the time does decrease, it is not

significant. The final 5 degree series severely disrupts habit I, causing perseveration responses (which make time meaningless) and a comparatively large increase in habit II time results for a positive series. The exceptions provided by these negative cases present problems not only of technique but of basic premises.

Group No. 3 is composed of two completely negative records, one of which is presented in Table IV. Although habit I is clearly dis-

TABLE IV

SUMMARY OF DATA OF RAT NO. 11

	Discrimination I				Discrimination II			
	Errors	Mean time	t	P	Errors	Mean time	t	P
Control runs.....	1	8.09			0	4.43		
Experimental runs								
60°.....	1	9.81	1.19	.2	0	3.70	.48	.6
30°.....	0	9.3	.86	.4	0	3.4	.69	.5
15°.....	6	14.12	4.09	.001	0	4.8	.64	.5
10°.....	5	14.53	3.68	.001	0	3.9	.35	.7
5°.....	1	10.54	1.83	.07	0	3.9	.09	.9

turbed, in no series does habit II reflect this disruption. The first two experimental conditions seem not to affect the strengths of either habit, and are thus of no significance, positive or negative. The last three variations, however, are striking negative examples. Highly significant time increases, plus two large error increases in habit I, are not followed by time or error increases in habit II as our hypothesis would predict.

While it should be kept in mind that our problem is most accurately discussed in terms of individual cases, and that group results tend to obscure many important aspects of the data, it is interesting to note that of 61 experimental series, 41 are clearly positive results, 15 are clearly negative, and 5 do not bear on the problem.

DISCUSSION

The results give evidence of the function of generalization of inhibition effects within a habit pattern. The implied hypothesis that there should be an increase in degree of disruption of habit strength in both habits with increasing levels of experimental difficulty has not been verified. We must not forget, however, that our orderly and logical progression of difficulty levels are not necessarily psychological levels of increasing difficulty. By analogy, we frequently note that in tasks of supposedly increasing levels of difficulty —for example, Lincoln Hollow Square, Knox Cubes, and so forth—

a human subject may fail an 'easy' level and then pass an assumed harder one. In human subjects the explanation is often found in the fact that the increased difficulty of the task is offset by an increase in effort and energy. As for our rats, the studies of concept formation in animals may suggest that the problem could have been solved in terms of relative and not absolute distinctions, much in the manner of Köhler's chicks that learned to respond to the grayer of two papers.

Although not quantitatively determined, there is evidence of a small degree of positive relationship between the amount of disruption of habit I and the amount of the generalized disruption of habit II. Verification of this must await an improved technique.

The large individual variation in our data presents a further problem. A guess that the susceptibility of the organism to generalization effects may bear some relation to the rate and nature of the habit acquisition might be tested by a comparison of the individual learning curve of each habit in the pattern and degree of generalized inhibition. The records of rats Nos. 5 and 11 are suggestive of this hypothesis. Rat No. 5, a positive case, showed an initial drop in efficiency when the two habits were first paired. Habit I dropped from 80 percent correct to 30 percent. Habit II remained at 90 percent efficiency, while 80 additional trials were necessary to regain a sufficient mastery of habit I under patterned conditions. Thus, we might assume that habit I was relatively unstable and would tend to break down under novel conditions. In comparison, rat No. 11, a negative case, acquired both habits rapidly. No drop in efficiency was caused by pairing the habits. This suggests the hypothesis that habits which are acquired quickly and easily, and habit patterns that are well knit together, tend to generalize or transmit extinction effects to a lesser degree than more difficult habits and less unified habit patterns.

As we have noted, the results of the experiment should be seen only in its relationship to the larger picture of conditioning as an inclusive behavior principle. As long as experiments of this nature are viewed as discrete problems and the experimentalist fails to point out its place in the stimulus-response theory, his contribution is minimized. The frequent misunderstanding of conditioned response theory as an atomistic approach incapable of dealing with the unified or molar nature of behavior is in part due to this tendency. It would seem profitable for the experimentalist to direct his attention toward more complex behaviors composed of interrelating patternings of habit responses. This necessity demands bolder experimental design and somewhat bolder application.

While the behavior in the present study is not very complex,

it is at least a habit *pattern*. Generalization phenomena are particularly applicable to complex habit patterning, characteristic of the fluid life situation, and thus more easily demonstrated, but one feels confident that application of other basic tenets of conditioning to more complex behavior is even now feasible.[1]

Over-interpretation is, of course, to be avoided, but on the other hand, failure to expose the full implications in terms of true life situations tends to relegate conditioning to the status of a special laboratory artifact. We note, for example, that an emotional disturbance or sudden change in the stimulating situation may make itself felt not only in the specific area of disturbance, but also in other aspects of the individual's life. However, the descriptive and predictive value of this observation is small. If such behavior could be seen in terms of generalization of inhibition effects from response pattern to response pattern (and it remains to the experimentalist to investigate the quantitative laws involved), an improvement of great value would be effected. This is more than a mere renaming, for the tangible and objectively defined process of the latter statement permits prediction and investigation not present in the original general and abstract observation. This is not meant to imply that in any specific case only one phenomenon would be involved. Perhaps a careful examination of many of our confusing psychological concepts in terms of conditioning would be englightening.

Conclusions

Experimental demonstration of generalization of inhibition effects within a habit pattern has been presented. A statement of this phenomenon would be to the effect that environmental variation or difficulty experienced by one habit of a response pattern tends to inhibit all other reaction tendencies which are associated with it in the total pattern.

The data suggest a quantitative relationship between the amount of difficulty experienced in one habit and the amount of generalized inhibitory effects transmitted to another habit in the same response pattern.

The phenomenon shows great individual variation. The hypothesis is suggested that the susceptibility of the organism to generalization effects depends upon the rate and the nature of the habit acquisition.

The necessity of utilizing more complex behaviors for experimental investigation is noted.

(Manuscript received April 24, 1944)

[1] Some of Hull's work is illustrative of this. Unfortunately, most of it is as yet unpublished.

BIBLIOGRAPHY

1. ELLSON, D. G. Quantitative studies of the interaction of simple habits. I. Recovery from specific and generalized effects of extinction. *J. exp. Psychol.*, 1938, **23**, 339–358.
2. HOVLAND, C. I. The generalization of conditioned responses: The sensory generalization of conditioned responses with varying frequencies of tone. *J. gen. Psychol.*, 1937, **17**, 125–148
3. HOVLAND, C. I. The generalization of conditioned responses: II. The sensory generalization of conditioned responses with varying intensities of tone. *J. genet. Psychol.*, 1937, **51**, 279–291.
4. HULL, CLARK L. *Principles of behavior.* New York: D. Appleton-Century Company, 1943.
5. HULL, CLARK L. The concept of the habit family hierarchy and maze learning. *Psychol. Rev.*, 1934, **41**, Part I, 33–52; Part II, 134–152.
6. HULL, CLARK L. Mind, mechanism, and adaptive behavior. *Psychol. Rev.*, 1937, **44**, 1–32.
7. HULL, CLARK L. The mechanism of the assembly of behavior segments in novel combinations suitable for problem solution. *Psychol. Rev.*, 1935, **42**, 210–245.
8. PAVLOV, I. P. *Conditioned reflexes.* London: Oxford University Press, 1927.
9. RAZRAN, G. H. S. Studies in configural conditioning. VII. Ratios and elements in salivary conditioning to various musical intervals. *Psychol. Rec.*, 1938, **2**, 370–376.
10. WENGER, M. A. An investigation of conditioned responses in human infants. *Univ. Ia. Stud. Child Welfare*, 1936, **12**, 9–90.
11. WICKENS, D. D. The simultaneous transfer of conditioned excitation and conditioned inhibition. *J. exp. Psychol.*, 1939, **24**, 332–338.
12. WICKENS, D. D. Studies of response generalization in conditioning. I. Stimulus generalization during response generalization. *J. exp. Psychol.*, 1943, **33**, 221–227.

EXPERIMENTAL TRANSFER OF CONDITIONING IN DOGS [1]

BY DAVID T. GRAHAM

It is sometimes found in conditioned response experiments that a stimulus can acquire the capacity to evoke a response without having been previously associated with it, even when the operation of known principles of generalization has been ruled out. This phenomenon has come to be known as transfer of conditioning, and it is of considerable theoretical interest because it seems at first glance to be inexplicable by classical conditioning principles.

Conditioning experiments in which transfer has been demonstrated may be tentatively divided into three classes. First, a response conditioned to one stimulus may be elicited by another stimulus because the two stimuli, both originally neutral, had been associated many times. This has been described as 'learned stimulus equivalence.' Second, a stimulus after being conditioned to one response may be found able, without direct training, to evoke another response. This has been said to show 'response equivalence.' [2] Third, both phenomena may occur. It is possible that a single explanation might apply to experiments of all three kinds.

An example of the first class is the experiment of Brogden (1). He presented dogs with 200 combinations of bell and light, and then conditioned foreleg flexion to one of the stimuli. When this conditioning had been established, it was found in six of eight dogs that the other stimulus also elicited the response. Prokofief and Zeliony (11) report an experiment with human *S*s which is similar in principle.

Wickens (16) provided an example of the second class. He found that a conditioned flexion response of the fingers changed to extension if the hand were placed prone rather than supine on the electrodes. Gibson, Jack and Raffel (3), Gibson and Hudson (2), and Kellogg and Walker (7) also found transfer in analogous experiments.

The work of Shipley (13) is the outstanding demonstration of the third class of transfer situation, though the experiments of Miller

[1] Presented in partial fulfillment of the requirements for the degree of Master of Arts in Yale University, 1941. The writer wishes to express his appreciation to Dr. Donald G. Marquis for many helpful suggestions and criticisms.

[2] The term 'response generalization' has also been applied to transfer experiments. It seems wiser to restrict its use to cases in which the conditioned stimulus, without any change in other stimulus components, evokes other responses than the one conditioned to it, as in the experiment of Kellogg and Wolf (8).

and Konorski (10) and some of those of Prokofief and Zeliony (11) likewise fit this category. Shipley put 15 *Ss* through a two-stage conditioning process. The first stage consisted of 45 pairings of a flash of light with a tap on the cheek delivered by a small padded hammer. This presumably established conditioning between the flash and the unconditioned response to the tap, i.e. a wink. The second stage consisted of 45 pairings of the tap on the cheek with a shock to the index finger. This training presumably produced conditioning between the tap and the proprioceptive stimuli arising from the response to the tap (the wink), and the finger withdrawal. Immediately following this training the *S* was twice presented with the flash. Although the flash had never been associated with the finger withdrawal, nine of the 15 *Ss* responded with finger withdrawal on one or both of these test trials.

Control groups, for which the possibility of learning either the first or second stage was not present, gave (with one exception) no transfer responses. Shipley therefore concluded (p. 388) that "it seems evident that it is necessary for both of these conditionings to be established for this response to occur with any degree of regularity."

Lumsdaine (9) has repeated and extended Shipley's work, but his results are not available in complete form.

The present experiment is similar to that of Shipley. Dogs were first conditioned to lift the right hindleg to the sound of a buzzer by the use of shock as the unconditioned stimulus. When this response had been learned, the animals were put through a second state of training by which they were taught to lift the right foreleg when the right hindfoot was shocked. At the conclusion of these two stages, tests were made to determine whether or not lifting of the forefoot would occur to the sound of the buzzer, even though there had been no association between them.

This procedure differs from Shipley's in that the use of animals rules out any peculiarly human attitudinal or volitional components, and, further, permits experimental interference to a far greater degree than is possible with human beings.

The plan of the experiment may be summarized as follows:

		Hindleg shock ↘
Step I	Buzzer — — — — — — — — — →	Hindleg flexion
Step II	Hindleg shock ↘	Foreleg shock ↘
	Hindleg flexion — — — — — →	Foreleg flexion
Step III	Buzzer — — — (Hindleg flexion?) — →	Foreleg flexion

Subjects, Apparatus and Procedure

Eight small to medium-sized mongrel dogs were used in the experiment. Four of the animals constituted the experimental group, and there were two control groups of two dogs each.

During training the dog stood in a wooden stock clamped on a table, with the head held in a wooden collar, and the chest and belly resting on a canvas band. All paws rested on wire grids, through which shock could be administered as desired. Freedom of movement of the legs was restricted to some extent by canvas straps buckled around the legs. From the buckles on the two legs which were used in training lengths of fishline passed to levers writing on a wax-paper polygraph. Rubber bands were attached to the levers with tension just sufficient to draw them back to the baseline position if the leg was not flexed.

The time of presentation of the conditioned and unconditioned stimuli was recorded by means of electro-magnetic markers. The conditioned stimuli employed were an electric buzzer and electric light. These were fastened about 12 in. in front of the dog's head, and slightly above it. The unconditioned stimuli were shocks to the paws, administered either from the 110-volt alternating house-current, or from the Muenzinger-Walz shocking apparatus. In either case, the intensity of the shock was approximately regulated to the lowest point which elicited a distinct flexion, and was changed from time to time during the sessions as the animal's response indicated.

All dogs were given one or two habituation sessions, depending on the amount of struggling they showed, in which they were put in the stock for half an hour without the presentation of any stimuli. Training therefore began on the second or third day.

For experimental dogs A and B the procedure in the first stage consisted of 25 pairings per session of the sound of the buzzer with shock to the hind foot. Trials were spaced at intervals of 15 to 45 sec. The buzzer was sounded approximately three sec. before the shock was given, but no attempt was made to keep this interval absolutely constant. If the foot was raised from the grid before the expiration of this time, no shock was given. Training was continued until a criterion of 20 avoidance responses in 25 trials was reached.

On the succeeding day the second stage of training was begun. A shock to the hind foot, not preceded by the buzzer, was followed by a shock to the right forefoot, as soon as the hindleg had responded. The criterion of learning in this stage was likewise 20 conditioned responses in 25 trials. Immediately upon the achievement of this criterion, the buzzer was sounded for approximately five sec., not followed by shock to either leg, and the response noted. Several buzzer trials were given and control presentations of the light, which these animals had never seen, were interspersed among the buzzer trials.

For experimental dog C the procedure was much the same, except that in preliminary work it received 50 pairings (in two sessions) of light with shock to the left foreleg. From that point, the training proceeded exactly as with dogs A and B.

Experimental dog D was trained in the first stage to lift the left foreleg in response to light. The second stage consisted of pairings of left foreleg with right hindleg shock. This dog, however, never did better than 16 conditioned hindleg retractions in the second stage, and since from this point its performance seemed to be growing more erratic, it was tested on a day when it gave only five such responses. The final test stimulus was, of course, the light.

To determine whether or not both stages of training were necessary for the elicitation of the test transfer response, and to rule out the possibility that sensitization or 'pseudo-conditionin' might account for the transfer, two control groups of two dogs each were run. In one of these opportunity for learning of the second stage only was presented; in the other, only the first stage could be learned.

The first group was given 13 days of training, with sessions of 50 soundings of the buzzer, unaccompanied by shock, alternating with sessions of 50 right hindleg shocks, unaccompanied by the buzzer. The total number of shocks and buzzer-soundings was equal to that received by the slowest learner of the experimental dogs, but in the controls, as expected, no flexion of the hindleg in response to the buzzer ever occurred. The latter were then trained on the second stage, exactly as were the experimental dogs, until this had been learned. They were then tested with the buzzer.

The second control group learned the first stage exactly as did the experimental dogs. In place of the second stage, days of 50 right hindleg shocks alternated with days of 50 right foreleg shocks. This lasted for 16 days, or until the number of shocks received equalled that for the slowest learner of the experimental dogs. These animals were then likewise tested with the buzzer.

Results

All four experimental dogs showed transfer of conditioning: that is, they responded on the final tests to the conditioned stimulus of the first stage with the conditioned response of the second stage (see Table I). Concretely, dogs A, B and C flexed the right foreleg in response to the buzzer on the test day; dog D flexed the right hindleg in response to the light. Dogs A and B made no response to the light, which had never been turned on during their training; dog D made no response to the buzzer, which had never been sounded during its training. Dog C, however, responded to both the light and the buzzer. The explanation of this will be considered below.

TABLE I

Summary of Results

Dog:	Experimental group				First control group		Second control group	
	A	B	C	D	1	2	1	2
Trials to learn first stage	125	350	300	125	—	—	200	475
Trials to learn second stage	275	700	125	575*	50	125	—	—
Transfer responses on first test day as fraction of tests	4/4	3/9	10/10	6/6	0/5	0/5	?	0/5

* Never reached the criterion of 20 conditioned responses in 25 trials.

Neither of the two control dogs of the first group made any response whatever to the buzzer in five trials on the test day. One of the dogs in the second control group responded on the test day with violent struggle, involving movement of all four legs, which was a return to its behavior in the early days of training. Since in the second stage the dog showed increasing restlessness and spontaneous flexion of both right legs, and since the response to shock to either foot, despite the fact that shocks to the two feet had never been paired, was almost always some movement of both legs, the data for this animal are extremely equivocal. The other dog in the second group responded to the buzzer with hindleg flexion, the response learned in the first stage, but did not lift the foreleg.

The transfer response showed a surprising stability, although it was never reinforced. With dog A, for instance, it occurred four times in 12 trials four weeks after the test, and dog C gave the response more than two months thereafter, although after four months it had disappeared. Dog B responded only on the test day, and dog D for only six days.

It was often found when the test stimulus was given that only the transfer response occurred, and not the response which had been

originally conditioned to it. In dog A this occurred in about three-quarters of the successful test responses, and in dogs B and C in about half. In many of the cases in which the hindleg did flex, the flexion occurred after the transfer response of the foreleg had already taken place. Therefore, in only about one-quarter of the cases did the responses on the test trial occur in what was the expected order: i.e., hindleg flexion followed by foreleg flexion. It is, however, difficult to determine the exact order of events, because contraction of the hindleg flexors may have occurred without actual leg movement, and, indeed, increased tension in the hindleg could sometimes be observed when the foot was not raised from the grid. A record of such tension did not, of course, appear on the polygraph.

One other feature of the data deserves consideration. It was noted that in the second stage training of dogs A, B and C, the conditioned stimulus (hindleg shock) sometimes failed to elicit its unconditioned response (hindleg flexion), but did elicit the response which had been conditioned to it (foreleg flexion). This effect was quite irregular, and occurred in only about one-sixth of the successful trials. It suggests some sort of 'drainage' phenomenon in conditioning.

Discussion

The significance of this experiment, as of Shipley's (**13**), lies primarily in showing that with a well-defined experimental conditioning situation, it is possible for a stimulus to elicit a response with which it has never been associated. The explanation of this transfer is still to be considered.

The following possibilities suggest themselves.

1. The repeated shocking of the animals might have sensitized them to respond by foreleg flexion to a wide variety of stimuli, without conditioning having necessarily taken place. Such a phenomenon has been demonstrated by Grether (**4**) and Sears (**12**), and been given the name 'pseudo-conditioning.' This possibility is ruled out in this experiment by the absence of response to the buzzer in the two control groups, and by the fact that the novel stimulus, light, did not produce the transfer response.

2. The transfer might be accounted for by the phenomenon called by Pavlov 'irradiation' and by Hull (**6**) 'primary generalization,' from the hindleg shock to the buzzer. The first control group rules out this possibility.

3. Transfer might be mediated by the phenomenon, which is on a much less firm experimental basis, of 'response generalization.' According to this view, any conditioned stimulus which elicited hindleg retraction would have a certain tendency to elicit other responses,

specifically in this case foreleg retraction. The results in the second control group (although the data for the first dog are unsatisfactory) militate against this possibility.

Shipley recognized the next two hypotheses which, since this experiment parallels his, are also applicable here.

4. A 'generalization of conditioning' factor, which operates in such a way that any conditioned stimulus tends to call forth any conditioned response, though there has never been any association between them, might be responsible for the transfer. There apparently exists no direct experimental evidence in support of this view.

5. Any two stimuli, (1) by virtue of simple association a number of times, or (2) by being both associated with the same response, might become functionally equivalent in the sense that a new response conditioned to either one of them could be elicited by the other.

The work of Brogden already mentioned lends some support to the first of these possibilities. The second supposes that because the buzzer and the hindleg shock had both been repeatedly associated with hindleg flexion, the foreleg flexion which is evoked by the latter may also be evoked by the former. There is some evidence in its favor from the well-known Pavlovian phenomenon of conditioned inhibition and secondary extinction. Shipley (**14**) has also produced evidence that some sort of transfer of training can be produced between two stimuli which are both conditioned to the same response.

6. On the basis of his experiments, Shipley (**15**) came to the conclusion that the most probable explanation of the transfer response lay in the process of chain-conditioning. This is also the position that Hull takes (**6**).

Translated into the terms of this experiment, this hypothesis states that the second stage conditioning of the foreleg flexion takes place not only to the hindleg shock stimulus, but also to the proprioceptive stimuli arising from the flexion itself. When the test presentation of the buzzer occurs, it will evoke not only hindleg flexion, but also foreleg flexion, since the latter has been conditioned to the proprioceptive stimuli arising in the hindleg.

The apparently aberrant behavior of dog C is in harmony with this position. It responded to the light on the test day because in its early training the left foreleg had been conditioned to flex to light. In the second stage of the regular procedure, when the right hindfoot was shocked, both it and the left foreleg responded, as apparently unconditioned flexions. Consequently proprioceptive stimuli from the left foreleg as well as the right hindleg were conditioned to right foreleg flexion, and therefore when the left foreleg flexed in response to the light, the right foreleg also responded.

The chain-conditioning hypothesis differs from (6) in that, al-

though both recognize the necessity for two stages of training, the neurological mechanism invoked by the latter would involve some central 'set' or 'short circuit.' The former, as its name implies, requires the transfer response to be mediated through the complete chain of stimuli and responses which have been postulated above.

This is undoubtedly the most attractive formulation from the traditional conditioning point of view, and may also be applied to experiments of the first two classes. Against it, however, is the inversion of the expected order of responses on the test day, an inversion which was also found by Lumsdaine (9). This is not crucial, since incipient movement sufficient to set up proprioceptive stimulation may have taken place in both cases before foreleg flexion, but it does at least support the possibility that both responses occur as the result of the development of some central set, as Hilgard and Marquis have pointed out (5).

Further investigation of this hypothesis is possible by using the technique of this experiment and employing spinal anesthesia in the experimental dogs to determine whether elicitation of the transfer response is still possible after blocking nervous impulses to and from the hindleg.

Summary

Transfer of conditioning was produced in four dogs by putting them through a two-stage conditioning process such that the unconditioned stimulus for the first stage was the conditioned stimulus for the second stage. During the first stage, conditioning of right hindleg flexion to the sound of a buzzer was established by the use of shock as the unconditioned stimulus. The second stage of training conditioned right foreleg flexion to the right hindleg shock. In one dog a light instead of a buzzer was used, and contralateral flexions were conditioned. At the conclusion of this training, all animals responded to the conditioned stimulus of the first stage with the conditioned response of the second stage. Control groups, for which the possibility of learning either the first or second stage was not present, gave no transfer responses. Transfer thus did not occur unless both conditionings were established. In many cases, the transfer response occurred directly, without appearance of the postulated mediating response of the first stage.

(Manuscript received April 29, 1944)

Bibliography

1. Brogden, W. J. Sensory pre-conditioning. *J. exp. Psychol.*, 1939, 25, 323–332.
2. Gibson, J. J., & Hudson, L. Bilateral transfer of the conditioned knee-jerk. *J. exp. Psychol.*, 1935, 18, 774–783.

3. Gibson, J. J., Jack, E. G., & Raffel, G. Bilateral transfer of the conditioned response in the human subject. *J. exp. Psychol.*, 1932, **15**, 416–421.
4. Grether, W. F. Pseudo-conditioning without paired stimulation encountered in attempted backward conditioning. *J. comp. Psychol.*, 1938, **25**, 91–96.
5. Hilgard, E. R., & Marquis, D. G. *Conditioning and learning.* New York: Appleton Century, 1940.
6. Hull, C. L. The problem of stimulus equivalence in behavior theory. *Psychol. Rev.*, 1939, **46**, 9–30.
7. Kellogg, W. N., & Walker, E. L. 'Ambiguous conditioning,' a phenomenon of bilateral transfer. *J. comp. Psychol.*, 1938, **26**, 63–77.
8. Kellogg, W. N., & Wolf, I. S. Changes in general behavior during flexion conditioning and their importance for the learning process. *Amer. J. Psychol.*, 1940, **53**, 384–396.
9. Lumsdaine, A. A. Conditioned eyelid responses as mediating generalized conditioned finger retractions. *Psychol. Bull.*, 1939, **36**, 650.
10. Miller S., & Konorski, J. Le phénomène de la généralisation motrice. *C. R. Soc. Biol.* Paris, 1928, **99**, 1158.
11. Prokofief, G., & Zeliony, G. Des modes d'associations cérébrales chez l'homme et chez les animaux. *J. de Psychol.*, 1926, **23**, 1020–1028.
12. Sears, R. R. Effect of optic lobe ablation on the visuo-motor behavior of the goldfish. *J. comp. Psychol.*, 1934, **17**, 233–265.
13. Shipley, W. C. An apparent transfer of conditioning. *J. gen. Psychol.*, 1933, **8**, 382–391.
14. Shipley, W. C. Studies of inhibitions in conditioned response. *J. gen Psychol.*, 1934, **11**, 46–64.
15. Shipley, W. C. Indirect conditioning. *J. gen. Psychol.*, 1935, **10**, 337–357.
16. Wickens, D. D. The transference of conditioned excitation and conditioned inhibition from one muscle group to the antagonistic muscle group. *J. exp. Psychol.*, 1938, **22**, 101–123.

A COMPARISON OF FINGER TREMOR WITH THE GALVANIC SKIN REFLEX AND PULSE *

BY JOHN W. FRENCH

Princeton University

Efforts to investigate mental processes have included studies of overt behavior, introspection, mental tests, and physiological processes. Among the physiological processes studied for this purpose are the electroencephalograph and those which have received much attention in lie detection work, namely, blood pressure, galvanic skin reflex, pulse, and respiratory changes. It is the purpose of this investigation to find out whether finger tremor is a physiological process which has the attribute of a good experimental tool for studying the contents of the mind.

Jacobsen and others have shown the importance of the muscular counterparts of thought. Of all the muscles which may reflect thought those of the tongue are probably most important. Because of the great activity and importance of our hands, the digitalis muscles may well be second in importance, and they are far more easy to study than the tongue muscles.

History.—It was not until 1897 that Eshner (**4**) convinced the world that muscle tremor was a normal phenomenon. He measured it by placing the *S*'s finger on a tambour connected with a kymograph. Since then a variety of different types of apparatus have been used. Many of the earlier ones, using tambours or mechanical lever systems, measured finger pressures rather than free finger movements. Even the ingenious electrical recording apparatus of Travis and Hunter (**10**) restricted the finger movements. Binet (**2**) was the first to record finger tremor photographically. He photographed the movements of a 'grain of wheat' bulb attached to the finger tip, but was not able to obtain clear records by this means. Beale (**1**) attached a spherical mirror to the finger tip and photographed the reflection of a light source from this mirror. He did not, however, obtain sufficient magnification for a clear record. Mehrtens and Pouppirt (**6**) used a good system for magnification by optical levers, but did not calibrate their apparatus. Sollenberger (**8**) used an apparatus which combined freedom of finger movement with adequate magnification and accurate calibration. He attached a small

* From the Psychological Laboratory, Princeton University.

piece of wire to a thimble worn by the *S* and photographed its shadow as it vibrated in a parallel beam of light.

From Eshner forward all workers on finger tremor report a fundamental frequency of 8–13 double vibrations per sec. Travis and Hunter (**10**) claim to have found tremor frequencies in the neighborhood of 40–50 per sec. and of 150–300 per sec. They reported that their records show these higher frequencies to be superimposed upon the 8–13 per sec. wave. Hill (**5**) reported frequencies ranging up to 75 vibrations per sec. Contrary to those who came before them, Young (**11**) and Sollenberger (**8**) emphasize the irregularity rather than the regularity of the response. When Sollenberger counted each observable reversal in direction as the beginning of a new half cycle, he found frequencies averaging around 12 per sec. He believes that regularity of the tremor record must be caused by inertia in the apparatus and that the high frequencies observed by others are artifacts.

A beginning has been made in finding the significance of tremor. Tremor and the GSR have been found by Sherman and Jost (**7**) to show larger responses in neurotic children than in normal children. Bousfield (**3**) found tremor increased with fatigue. Travis and Hunter (**10**) show how it varied after conditions of rest, exercise, hot and cold. They also show that muscle potentials in the forearm increased momentarily each time a tremor cycle starts. Sollenberger (**8**) relates tremor to muscle tension, since voluntary tensing of the finger increases tremor. His *S*'s tremors were high while they repeatedly subtracted seven from a number, giving the answers out loud. He attributes this to the tension produced during mental work. All workers say there is much individual variability in the amount of tremor.

A logical step, in the study of finger tremor is to find how much it parallels other responses. If tremor correlates closely with a more easily recorded response such as the galvanic skin response, there is little use in studying it. It was the purpose of this experiment to find out whether finger tremor acted in a differential way to various mental processes and was independent of other responses, the galvanic skin response in particular. Toward this end an apparatus was arranged which would simultaneously record finger tremor, palmar skin resistance, and pulse on a single moving film. Travis and Cofer (**9**) have already found tremor to be independent of brain potentials.

Apparatus.—In order to record the three responses on a moving film, an American Optical Co. opthalmograph was found very suitable, because it not only provided a 35 mm. film moving at a regular rate of .5 in. per sec., but also supplied two camera lenses which focused on the film. An opthalmograph was, therefore, fitted out with attachments for recording the three responses.

Finger tremor: The *S* sat sideways in front of the instrument with his left forearm held vertically in a padded clamp and his elbow supported at a comfortable height. His forefinger, pointing upwards, bore a thimble. The thimble rested against a light wooden lever which magnified the tremor by 2.5. The lever was so light and its pressure against the thimble was so small that it could not be felt, and probably did not affect the tremor by any recordable amount. A very small convex mirror made from a blown bubble of glass was attached to the end of the lever. The reflection of a light source on this mirror was photographed by the opthalmograph, which magnifies a movement by 4. The magnification of lever and opthalmograph together is 10. Ideally, not even a light wooden splint should rest against the finger, but the reflecting mirror could not be placed directly on the thimble or finger, because slight finger movements toward or away from the camera upset the focus. The width of the film permitted a fluctuation of the finger tip no greater than 2.5 mm. The tremor was well within this limit, rarely exceeding .3 mm. in extent. With their arms and hands supported, it was easy for most *S*s to keep their finger tips in this restricted region most of the time without looking at their fingers or giving undue attention to the job of holding their finger in position. As a reminder to the *S*, an electric contact lighted a lamp whenever he moved his finger too far to the side.

Galvanic skin reflex: The inside of the third finger and thumb of the same hand were held by a pair of rubber cushions against tin electrodes. This device utilized these two palmar areas because they proved to be very satisfactory for galvanic skin reflexes and because a clamp in this position afforded a needed support to the hand. The electrodes were connected in simple series with a milliameter and a 50,000-ohm potentiometer using a 45-volt battery. The milliameter was placed so that a source of light was reflected from a minute mirror on its pointer into the other lens of the opthalmograph. Another potentiometer in parallel with the meter provided a 'bucking' potential which made the range of the *S*'s response coincide with the field of the camera. Signals on the record to indicate the times of stimuli and verbal responses were made by blinking the light source. A short break was thus made in the GSR record.

Pulse: A 5-in. wooden splint was fastened with collodion to the *S*'s wrist at the point where the pulse could be felt most strongly. The splint extended horizontally from the arm. Each beat of the pulse caused the end of the splint to jerk several millimeters to the side. A source of light was reflected from a small convex mirror fastened to the end of the splint. This reflection was directed by a lens and mirror system into the opthalmograph through the same lens used by the finger tremor.

Procedure.—Four men and one woman served as *S*s. The *S* was seated sideways to the apparatus so that tremor, GSR, and pulse could all be recorded from his left hand. The right hand remained completely free. It could be used in the procedure as required. Proper adjustment of the apparatus sometimes took as long as 20 min. The *S* was then presented with the following situations:

1. Rest. The record of the first rest period was discarded, since it appeared to be influenced by apprehension or unfamiliarity with the apparatus.
2. Four 3-sec. squeezes by the right hand on a hand dynamometer.
3. Rest.
4. Ten reaction time tests, where the *S* was given the signal 'ready,' and then, upon hearing a 'click,' was required to press a key as quickly as possible. In order to keep up the *S*'s motivation, the electric clock which measured his reaction time was made visible to him.
5. Rest.
6. Mental multiplication of eight pairs of 2-digit numbers, varying in difficulty so as to require from 6 to 20 sec. for computation. The answer was given out loud.
7. Rest.
8. A sudden loud noise presented only once.

Record.—In place of film, kodabromide paper 35 mm. wide was used in the opthalmograph. Each of the three records could move across the full width of the paper. Confusion when the records crossed was avoided by an adjustment of brightnesses of the records and by allowing the GSR record to be out of focus so that the other records could be read through it. Since the GSR is slow and regular in its movements, its being out of focus did not impair the accuracy to which it could be read. Plate I shows a sample strip of record paper. It was always read in this horizontal position, so that time passes from left to right.

The records were marked off by fine scratches into half-in. lengths. Since the paper travelled through the opthalmograph at the rate of a half in. per sec., these markings divided the records

into seconds. The markings were measured from the signal points in the GSR record. The reactions of the *S* during each of several seconds before and after a stimulus could then be analyzed.

Tremor: In order to measure the amount of tremor in each second, the record was projected on a screen so as to have a magnification of 10. The vertical extents of all the finger movements in each second were measured and totaled in one operation on a ruler. A typical measurement for one sec. would be 200 mm. Since the lever and lens in the apparatus produced a magnification of 10, and since the projector magnified the photographic record by 10, this measurement means that the tip of the finger travelled a total distance of two mm. during that second. The tremor frequency for each second was also measured. Following Sollenberger's method, each observable reversal in the direction of the record was counted as the start of a new half cycle.

GSR: This record was intentionally made off focus to avoid confusion with the other records. The blurred reflection of the light source produced on the paper a gray stripe about three mm. wide, which moved up when the skin resistance increased and moved down when it decreased. The distance of the edge of this stripe from the side of the paper at the beginning and end of each second was measured. The difference between these measurements was the net change for that second. The amount of change in skin resistance represented by a given rise or fall in the record varied from *S* to *S* according to the *S*'s resistance and the setting of the potentiometer. The smallest amount which could be read was .1 mm.; this amount represented a resistance change of from 60 to 120 ohms, depending on the *S*.

Pulse: Each heart beat was clearly marked on the paper by a downward loop in the pulse record. The distance between these loops was measured. For each second a value of the pulse rate in beats per min. was calculated.

From two to nine complete records of each situation other than 'sudden noise' were obtained from each *S*. There was only one record for each *S* of 'sudden noise.' Records which were incomplete, because the *S*'s forefinger touched the side guards or because the GSR suffered a deflection wide enough to throw it out of the field of the camera, were discarded.

Results.—The procedure provided for five situations: (1) squeezing a hand dynamometer, (2) mental multiplication, (3) finger reaction-time tests, (4) rest, and (5) sudden noise. The reactions to these situations are presented in Figs. 1–5. The graphs of all situations except 'sudden noise' present a composite of 20 or more single reactions. The graph of 'sudden noise' is a composite of the five *S*s' reactions.

The absolute value for the skin resistance is plotted at the end of each second. The values for tremor and pulse, on the other hand, are plotted at the mid-points of the seconds, since they represent the average value during the second.

The graphs show that finger tremor tends to rise rapidly upon stimulation and then to subside more slowly. With 'reaction time' and 'sudden noise' the rise is immediate, while with the dynamometer it has some latency. In the case of mental multiplication there is usually a drop in tremor, followed by a rise just before the answer is given. The high tremor level before the problem was stated appears to be a result of two factors: (1) a persistent high tremor level following the announcement that the situation involved mathematics; and (2) a high tremor level carried over from the previous problem.

The graphs of the galvanic skin reflex show a fairly constant pattern. Resistance rises during rest and is seen to be rising at the beginnings of all the graphs. It drops sharply about two sec. after a stimulus, and then renews its rise.

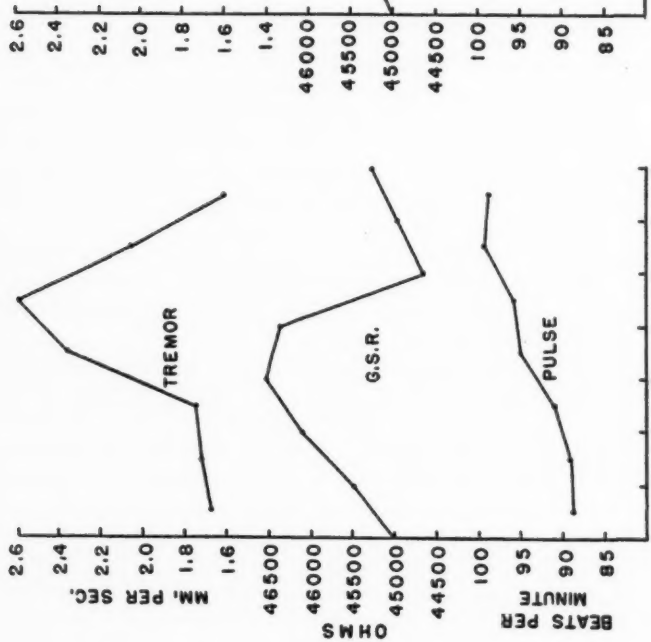

FIG. 1. Average reactions of the left hand while the right hand squeezes a hand dynamometer.

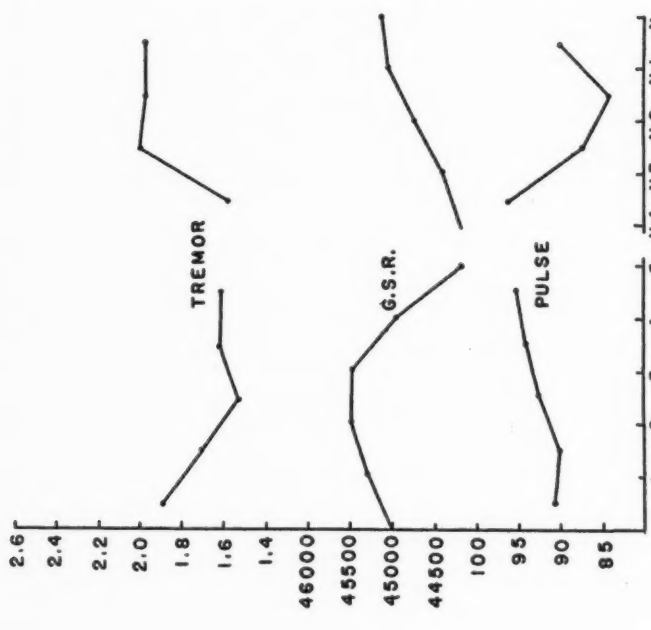

FIG. 2. Average reactions of the left hand during mental multiplication.

hand squeezes a hand dynamometer.

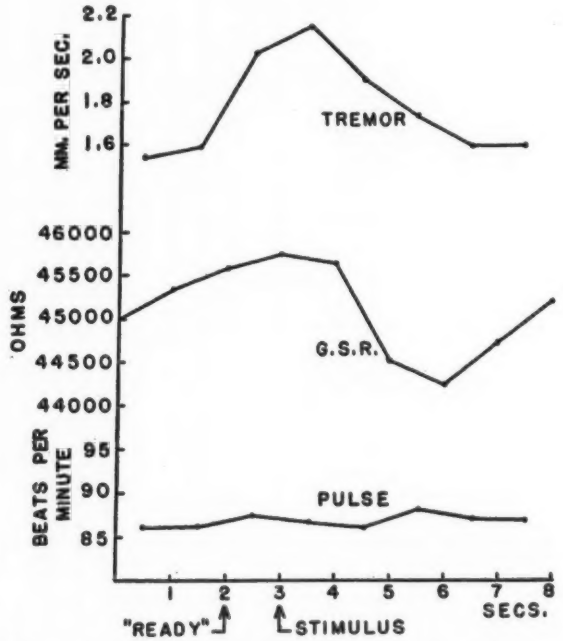

FIG. 3. Average reactions of the left hand during tests of the reaction time of the right fore-finger.

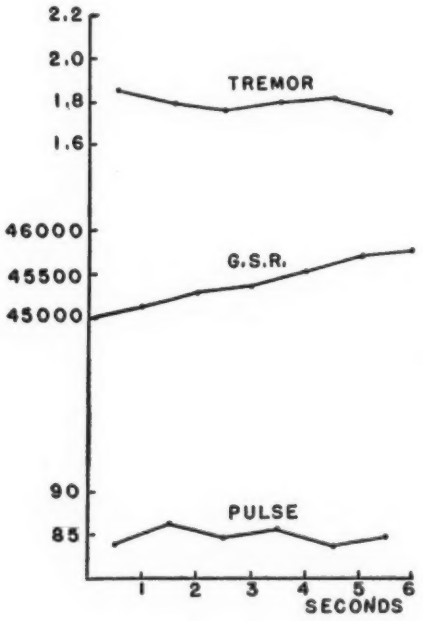

FIG. 4. Average reactions of the left hand during rest.

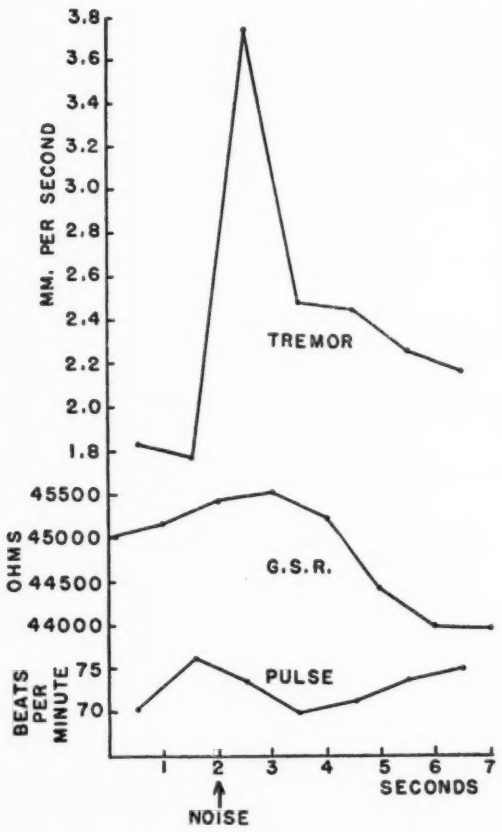

FIG. 5. Average reactions of the left hand upon the presentation of a startling noise.

The pulse does not show very marked changes, though the drop at the end of a multiplication problem turns out to be significant at the two percent level. There is also a rise while the *S* squeezes the dynamometer, but the data are not very complete in this instance.

Table I shows the reactions of the individual *S*s in each situation. The reaction may be defined as the difference between the levels of the *S*s' tremor, rate of change of skin resistance, or pulse taken before the stimulus and a few seconds after the stimulus. The particular two seconds used to compute the reaction are indicated by the subscripts of the symbol for the mean at the head of each column in the table. For example, consider the tremor reaction of Subject F to the dynamometer. The symbol for the mean at the top of the

TABLE I

MEANS, STANDARD DEVIATIONS OF THE MEANS, AND NUMBERS OF REACTIONS CLASSIFIED BY *Ss* AND SITUATIONS

Tremor Reactions (Change in tremor rate in mm. per sec.)

Subject	Dynamometer			Mental mult.			React. time			Rest			Noise	
	M_{12}	σ_M	N	$M_{4(8-9)}$	σ_M	N	M_{14}	σ_M	N	M_{17}	σ_M	N	M_{12}	N
L				.18	.17	4	**1.06**	.18	7	−.05	.29	4	.45	1
T	.80	.00	2	1.00	.26	3	*.72*	.16	9	.05	.12	4	.15	1
F	.25	.16	6	.07	.29	3	*.48*	.10	4	−.05	.21	4	3.85	1
R	2.00	1.30	4	**1.07**	.09	3	*.52*	.14	4	−.18	.29	4	4.05	1
H	.55	.19	4	−.03	.23	3	.23	.17	9	−.15	.20	4	1.25	1
M	*.45*			.46			*.60*			−.08			1.95	
σM	.14			.23			.14			.06			.83	

GSR Reactions (Change in rate of rise in resistance in ohms per sec.)

	M_{15}	σ_M	N	M_{15}	σ_M	N	M_{15}	σ_M	N	M_{17}	σ_M	N	M_{18}	N
L				−310	360	4	−1160	500	7	140	150	4	−60	1
T	−5240	3050	2	−3520	1650	3	−3230	400	9	0	30	4	−600	1
F	−600	130	6	−540	160	3	−1470	170	4	50	30	4	−390	1
R	−2680	1060	4	−400	200	3	−1320	600	4	60	30	4	−2280	1
H	−410	230	4	−660	360	3	−50	90	9	30	30	4	−450	1
M	−2230			*−1360*			*−1560*			60			−760	
σM	1130			460			420			30			400	

Pulse Reactions (Change in pulse rate in beats per min.)

	M_{17}	σ_M	N	$M_{4(8-1)}$	σ_M	N	M_{14}	σ_M	N	M_{17}	σ_M	N	M_{18}	N
L				−7.5	8.9	4	−5.2	4.8	7	−6.3	5.5	4	−4	1
T	26.0	6.0	2	*−17.0*	3.0	3	3.3	3.6	9	3.3	3.3	4	0	1
F	*1.8*	.7	6	−15.7	6.9	3	1.3	.8	4	0.0	.8	4		
R				−5.3	8.7	3	5.8	8.8	4					
H	0.0	2.3	4	−4.0	2.9	3				−1.3	4.4	4	5	1
M	9.3			*−9.9*			1.3			−1.1			.3	
σM	8.4			2.7			2.4			2.1			2.6	

column, M_{15}, bears the subscript 15, indicating that the reaction considered is that rise in the tremor line of Fig. 1 between the first and fifth points. The next two figures in the table show that Subject F squeezed the dynamometer six times, producing an average rise in his tremor of .25 mm. per sec.

Since the primary purpose of the experiment was not to discover the general reactions to these situations, only a small number of *Ss* were used and each *S* was presented with a given situation only a small number of times. Since the number of degrees of freedom for the means given in the table never exceeds eight, and is often very much less, high significance cannot be expected. However, in order

to show which reactions are the most promising for study, those means which are significantly different from zero at the 1 percent level are given in bold faced type, while those significant at the 5 percent level are given in italics.

No graphs or tables of tremor frequency are given, because this measure did not show nearly as high consistency as did total movement per sec. For each second, however, a count was made of the frequency or number of complete oscillations made by the finger tip. All perceptible reversals in the direction of the record were counted as starting a new half cycle. The range of frequencies was from 6 to 21 complete oscillations per sec. with only one *S* having frequencies above 16. The averages for the individual *S*s ran from 10 to 14. These values are in general agreement with those of Sollenberger, who used the same method of counting.

Discussion.—Sollenberger (**8**) devoted considerable space to a criticism of those investigators whose apparatus produced a distorted picture of tremor. Many of them measured only the fluctuating pressure of the finger on a tambour, rather than the motion which occurs when the finger is free. Others attached heavy apparatus to the finger so that its motion was influenced by the inertia of the apparatus. Sollenberger's photographs of a shadow cast by a wire projecting from a thimble worn by the *S* must show an almost completely true picture of tremor. He suggests that the irregular form of the tremor shown in his photographs was unobserved by others because of faulty apparatus.

In the present investigation the tremor apparatus was limited by the requirements of the GSR and pulse apparatus. A light plastic thimble was worn by the *S* and a lever bearing a mirror rested against it. Since the lever and mirror combined only weighed .4 gm., the inertia of this addition to Sollenberger's thimble could have had very little effect. The frequencies which could be recorded were determined by vibrating a stretched rubber band in contact with the lever. Frequencies up to 50 per sec. and amplitudes down to .01 mm. were easily legible in the record. Faster frequencies were unreadable, since the paper moved through the camera at a rate of only a half in. per sec. The lever was tested for internal frequencies of vibration by allowing it to snap against the thimble while the camera was running. The wood was sufficiently stiff so that no vibrations beyond the snap itself could be detected in the record. Whatever internal frequencies the lever possessed were of too small an amplitude to be seen. A further confirmation of the absence of inertia or of a fixed frequency may be seen from the fact that the tremor records were very irregular, as can be seen from Plate I and II. Although they are more difficult to read, they show the same irregular pattern that Sollenberger's do.

The present results are in general agreement with the findings of Sollenberger (8) and Young (11) that tremor is so irregular that at no point can its future course be predicted. The present results also

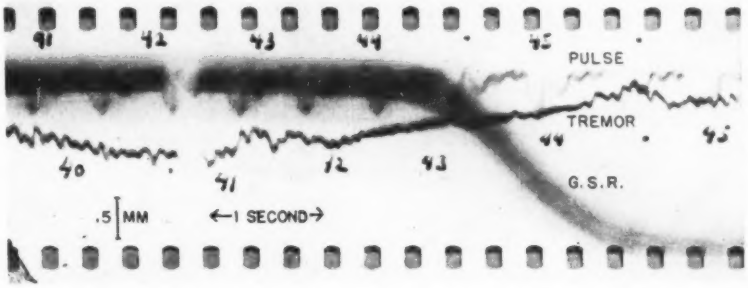

PLATE I. Segment of bromide paper showing records of pulse, tremor, and GSR of Subject T. The pulse record is displaced about 1½ sec. to the left of the others, as indicated by the numbers. The size of the tremor movements represented by the record may be judged by comparison to the .5 mm. scale line. The break in the GSR and tremor records marks the time of presentation of a multiplication problem. A typical reaction of tremor and GSR can be seen.

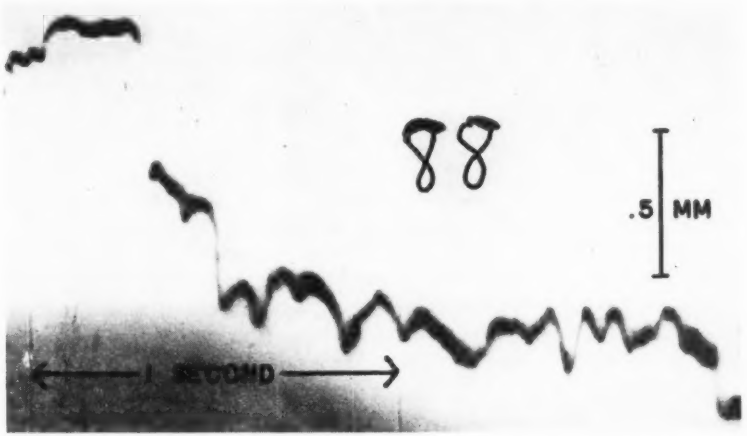

PLATE II. Enlarged view of tremor record showing evidence of a superimposed high frequency. The record is from Subject R while squeezing the dynamometer.

agree with these authors that there is a negative correlation between tremor frequency and amplitude. The large movements when they occur seem to obscure many small ones.

In determining frequency, Travis and Hunter (10) did not merely count peaks, but attempted to analyze their records into a series of

superimposed frequencies. They claim to have found an 8–12 per sec. rhythm with frequencies of about 40 and frequencies of about 150 superimposed upon it. Sollenberger denies the presence of frequencies above 16. The present study has not produced adequate records with which to settle this difference, because the apparatus was limited to frequencies below 50. By far the greater part of the present records showed complete irregularity as far as could be seen by inspection. Owing to the extreme irregularity of the tremor record a Fourier analysis seemed not to be worthwhile. However, there were several places in the records of four out of the five *S*s where a superimposed frequency seemed evident. These occurred in spurts usually lasting for less than a second. They never approached the limit of the apparatus in rate, being in the range from 25 to 40 per sec. These may be mere irregularities in the record. Plate II shows the longest of these spurts of possible high frequency. The fact that such spurts as these vary in frequency from 25 to 40 and fail to appear for such long periods is probably sufficient proof that they are not resonance frequencies in the apparatus.

Tremor has always been measured in terms of its frequency and amplitude. The author has varied from this system of measurement, because, as soon as a movement becomes so irregular as to be unpredictable, it no longer can be said to have a frequency. The so-called frequency can only depend upon the smallest fluctuation or hesitation which one is willing or able to count. Moreover, the average amplitude would be profoundly affected by the including or excluding of very small hesitations which would have to be averaged in as tremors of almost zero amplitude. The method of measurement used here made the decision about the small hesitations unimportant. As explained above, measurement was made of the total distance through which the finger tip moved during each second.

For purposes of comparison with previous investigations the total movement per sec. may be compared with average amplitude, because these two measurements correlate to a considerable degree. One part of the present results might appear to disagree with those of Sollenberger. He found that tremor amplitude was high during 'mental effort,' which consisted of continually subtracting seven from a number near 100 and given each answer out loud. In the present experiment, tremor was low during mental multiplication, but rose to a high level just before the answer was given. In Sollenberger's experiment, then, it is possible that the cause of the high amplitude of the tremor was the process of giving out loud the continuous series of answers rather than the mental effort as such.

Sollenberger believes tension to be a primary cause of finger tremor, because tremor amplitude increased when the finger is tensed.

Indeed his observation can be checked by closely observing one's own finger when it is tensed. The increase in tremor amplitude can be seen easily. In the various situations of this experiment an increase in tension may well account for the rises in tremor. The low amount of tremor during mental multiplication does not confute Jacobsen's assertion that muscle tension increases during mental work. Tension may well increase elsewhere in the body during mental multiplication, and then extend into the digitalis muscles when the answer must be given.

Conclusions.—The purpose of this investigation was to find out whether or not finger tremor would be useful to study as a correlate of mental processes. Toward this end tremor of the left forefinger, the galvanic skin reflex, and pulse were recorded simultaneously on a moving strip of bromide paper, while the *S* reacted to four situations: muscular work, mental work, reaction time tests, and sudden noise. The pulse rate did not show any consistent trends in any of the situations used in this experiment with the possible exception of a fall in pulse rate during mental multiplication. The amount of tremor rises rapidly immediately after a loud noise. It also rises immediately after the stimulus for a reaction by the right hand. The rise follows with some latency the request to squeeze a hand dynamometer with the right hand. During mental multiplication the amount of tremor decreases somewhat and then rises above the resting level just before the answer is given. In these four situations the skin resistance decreases rapidly about two sec. after the first stimulus. The tremor, then, is independent of the GSR, and has the important advantage of varying more with the situation. This variability may be enough to distinguish between some types of mental processes.

(Manuscript received April 27, 1944)

References

1. Beale, C. G. New method of recording tremors. *Arch. neurol. Psychiat.*, 1925, **14**, 751–757.
2. Binet, L. R. Etude technique du tremblement. *Pr. Med.*, 1919, **27**, 561.
3. Bousfield, W. A. The influence of fatigue on tremor. *J. exp. Psychol.*, 1932, **15**, 104–107.
4. Eshner, A. A graphic study of tremor. *J. exp. Med.*, 1897, **2**, 301–312.
5. Hill, A. V. The tetanic nature of the voluntary contraction in man. *J. Physiol.*, 1921, **55**, 14–16.
6. Mehrtens, H. G., & Pouppirt, P. S. Recording of tremor, new method, with some account of its clinical significance. *Calif. and West. Med.*, 1928, **29**, 184–186.
7. Sherman, M., & Jost, H. Frustration reactions of normal and neurotic persons. *J. Psychol.*, 1942, **13**, 3–19.
8. Sollenberger, R. T. A photographic study of tremor during postural contraction. *J. exp. Psychol.*, 1937, **21**, 579–610.
9. Travis, L. E., & Cofer, C. N. The temporal relationship between brain potentials and certain neuromuscular rhythms. *J. exp. Psychol.*, 1937, **21**, 565–569.
10. Travis, L. E., & Hunter, T. A. Tremor frequencies. *J. gen. Psychol.*, 1931, **5**, 255–261.
11. Young, I. C. A study of tremor in normal subjects. *J. exp. Psychol.*, 1933, **16**, 644–656.

LEARNING AS A FUNCTION OF THE ABSOLUTE AND RELATIVE AMOUNTS OF WORK[1]

BY MERRELL E. THOMPSON

State University of Iowa

I. Introduction and Statement of the Problem

The learning of white rats to discriminate between two alternative responses involving different distances or times to a goal situation has usually been interpreted in terms of the differen ttemporal delays of reward involved. In his recent book (7) Hull has suggested that a further factor—the differential amounts of work involved—must also be taken into account. He concluded from Grice's (5) experimental results with the alternative long-short path type of maze that if the temporal factor were completely equalized, the animals would nevertheless develop a preference for the shorter path. This expectation he based upon the assumption that a differential amount of work is required to traverse the long and short paths and that this factor would help to determine the relative strengths of the competing response tendencies.

Neither the long-short alternative path type of maze situation employed by DeCamp (3), Yoshioka (13) and Grice (5) nor the delay chamber situation used by Anderson (1) and Wolfe (12) has controlled both time and work variables. While the latter provided control of the time variable it neglected the possibility that the *S*s were more active (i.e., worked more) during the long delay than during the short delay periods. The long-short path situation provided for more work on one path than another but also involved differential delay periods. Grice's experiment showed that in this latter situation learning was more closely related to the relative distance (work) of the paths than to the relative times taken to run the paths. This suggests that in this type of situation the work variable is the more important of the two.

The problem of work as a factor in learning is also related to a wide range of experimental phenomena, subsumable *under the law of less work*, which have attracted the attention of such investigators

[1] This paper is the second of two studies constituting a dissertation presented to the Faculty of the Graduate College of the State University of Iowa in partial fulfillment of the requirements for the degree of Doctor of Philosophy. The writer is deeply indebted to Professor Kenneth W. Spence who directed the investigation.

as Crutchfield (2), Waters (10), Tsai (9), Gengerelli (4) and Wheeler (11). These writers have been content, for the most part, with showing that organisms do choose the less laborious method of attaining a goal. They have not, however, been concerned with the problem of the functional relationship between the relative amounts of work and learning.

The present experiment was aimed at investigating the learning of a discrimination between two responses which involved different amounts of 'work' in order to obtain food reward. The learning situation consisted of a T-Maze, the pathways of which led to food delivery mechanisms operated by levers which required differential amounts of pressure (weight) to depress. Keeping the ratio between the weights required to depress the levers constant ($H/L = 1.5/1.0$), four different groups of *Ss* were run at four different absolute weight values. The data thus provide evidence as to the functional relationship between rate of learning and the absolute value of the amount of 'work' involved in making the response.

II. Experimental Procedure

A. Apparatus

The maze employed in this experiment was a single choice-point one with two paths of equal length leading to food delivery mechanisms as shown in the floor plan in Fig. 1. The relative position of the light and heavy bar for any one animal could be changed by the utilization of two starting boxes. For example, all animals showing an initial left turning habit were always started from box 'A' while those showing a right turning preference were started from box 'B.' Thus, the location of the heavy bar was always on the same side in respect to the experimental room but differed in respect to the animal being run.

Constructed of unpainted white pine, the maze alleys were four in. wide, five and one-half in. high, and 10 in. long, and covered with hardware cloth. The short alley leading up to the choice point from the starting boxes was only two and one-half in. wide in order to reduce to a minimum the effect of following one wall up to the point of choice. Uniform illumination was maintained on both paths by suspending a single light over the center of the choice point. Extraneous sound cues were controlled by running the experiment in a sound-proof room, while the noise of the electric timer was controlled by mounting it directly over the light. A time record was kept for each run of every animal and included the time between the point when the animal left the starting box sufficiently to allow the door to be dropped and the point when the food bar was depressed.

The food-releasing apparatus used was modified after those used on Skinner type of box but possessed certain features which suited it for the present investigation. Thus, the amount of pressure required to release the food could be determined precisely, varied over an indefinite range, and maintained at a definite constant weight in any experimental situation; also, the apparatus could be used in a box or maze situation. In the present study two pieces of identical apparatus were constructed to be used at both ends of the simple T-Maze.

B. Subjects and training procedure

The *Ss* consisted of 54 male albino rats from the colony maintained by the Psychology Department of the State University of Iowa. At the beginning of the experiment they were between 150 and 200 days old. The *Ss* were assigned by random numbers to one of the four groups after being ranked according to weight—that is, the four heaviest animals were each assigned to one of the four groups at random, then the next four, and so on. Because of the care exercised to

make all group selections at random, it proved difficult to keep the mean and proportional weights of the animals constant from group to group; thus, the mean weights in gm. of the four groups of animals were as follows: Group I, 160.30; Group II, 180.84, Group III, 181.07, and Group IV, 166.14. These differences in mean weight of the animals from group to group cannot be considered as a relevant variable in this situation, since the rank order correlations between weight and learning were in no case significant, the largest correlation being .32.

After being assigned to the various groups all animals were given preliminary training in pressing the bar. The first phase of this training involved making 10 bar-pressing responses with the amount of weight required to depress the bar being 10 gm. Following this, the *S*s were given 20 more training trials with the weight being gradually increased until the last 10 trials required the same amount of pressure as required on the heavy bar in the experimental situation for the respective group, i.e., 15 gm. in the case of Group I, 30 gm. in Group II, etc.

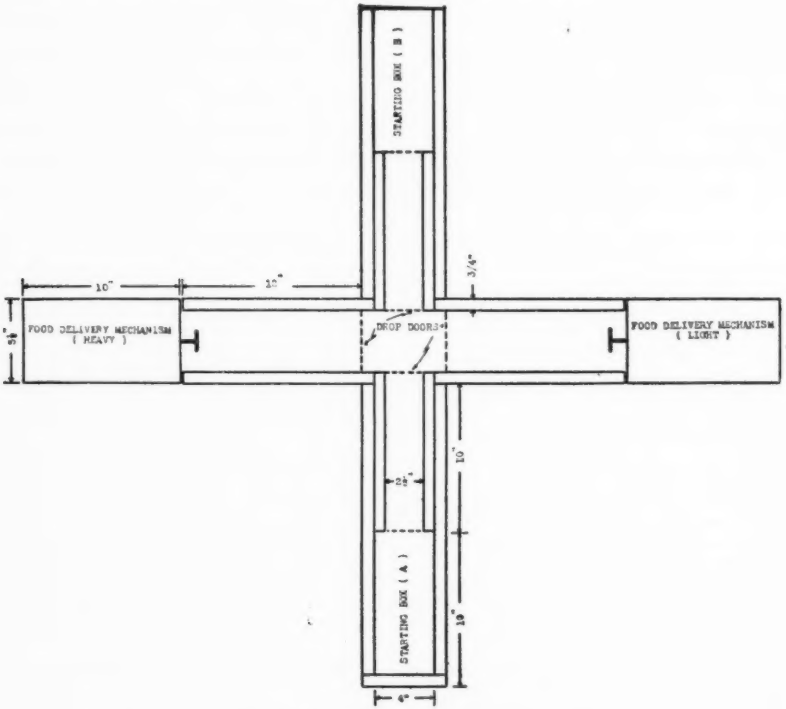

FIG. 1. Floor plan of the maze.

C. Learning series

The learning series in the experimental maze was begun the day following completion of the preliminary training. On the first trial the amount of pressure (weight) required to depress the levers was the same, viz., the heavy weight value of the group to which the animal belonged. The path chosen then became the path involving the heaviest weight (greatest amount of work) for that animal for the remainder of the experiment. Each *S* was given four runs the first day and eight thereafter. The first two runs in each block of four were free runs in which both paths were open; on the remaining two runs the animal was forced to take either one of the paths, so

that in the four trials two runs were made to each of the 'light' and 'heavy' paths. To avoid the development of a simple alternating response, the forced runs were arranged in such a manner as to produce one of the following patterns of choices during each block of four runs: RRLL, RLLR, LRRL, LLRR. Thus, when the first two free runs were made to the right (R) the forced runs were both made to the left (L), and so on. Forcing a response to one alley was accomplished by dropping a door in one of the pathways one in. beyond the point of choice.

In order to avoid alternation of response because of 'refractory phase' (6), animals were rotated in their runs in such a manner as to allow a minimum of 15 min. between all free trials, i.e., a run involving a free choice was never given until a period of 15 min. had elapsed from the previous run. The order of running *Ss* for each day was determined by a table of random numbers.

The learning series continued until each animal satisfied the criterion of choosing the path involving the least amount of work on the first two free runs in each block of four runs for three consecutive blocks of such trials, that is, six consecutive free runs to the path involving the least amount of work in depressing the lever. However, all *Ss* were discontinued after 80 trials if they had not satisfied this criterion and the number of their trials to learn was tabulated as 40, i.e., 40 pairs of trials on both paths.

The incentive consisted of a small pellet of the rat's regular diet (Purina Dog Chow) weighing an average of .15 gm., which was delivered when either lever was depressed. Immediately following the daily experimental period the animals were fed their daily ration which consisted of eight gm. of Purina Dog Chow.

D. Experimental conditions

Under the four different conditions of the experiment, the differential amount of pressure (weight) required to depress the levers was held at a constant ratio, that is, heavy/light weight ratio = 1.5/1.0. The four groups of *Ss* were run at four different absolute weight values as follows:

Group	N	Light weight	Heavy weight
I	10	10 gm.	15 gm.
II	15	20 gm.	30 gm.
III	15	30 gm.	45 gm.
IV	14	40 gm.	60 gm.

III. Experimental Results

The results of the present experiment are shown in Table I and are illustrated graphically in Fig. 2. From these data it can be seen

TABLE I

The number of the group is shown in the first column, and in the second column the number of *Ss* comprising each group. The third column gives the percent of animals in each group that reached the learning criterion of six consecutive free runs to the path involving the least amount of work, the fourth column shows the mean number of errors made in 40 free runs, and the fifth column gives the median number of pairs of trials (one trial on each of the two paths) required to reach the criterion.

Group	N	Percent of rats reaching criterion	Mean number errors	Median number trials
I	10	30.0	20.30	40
II	15	66.6	14.06	14
III	15	73.3	12.00	22
IV	14	92.8	7.71	10

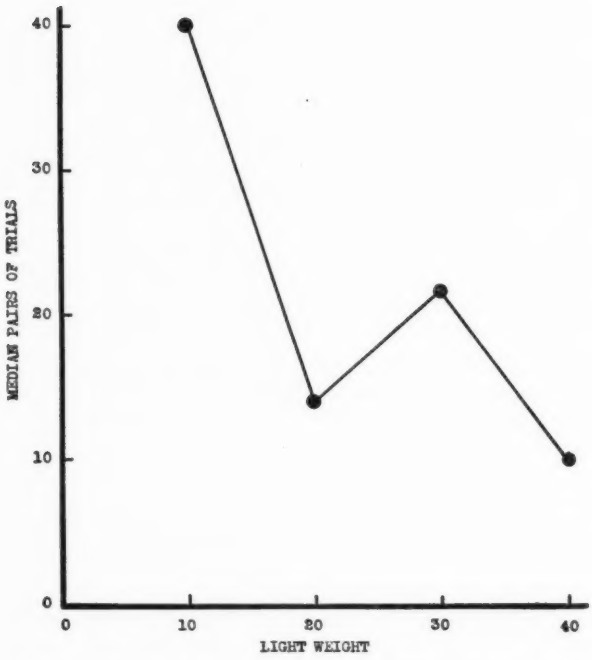

FIG. 2. The median number of trials on each of the two paths required for 100 percent selection of the path involving the least amount of pressure in depressing the bar plotted against the weight in gm. of the 'light' path.

that the effect of increasing the absolute weight values resulted, in general, in quicker learning as measured both by mean number of errors made in 40 free runs and median number of pairs of trials required to learn. The differences as measured by the median pairs of trials are statistically significant at beyond the one-percent level as shown by an analysis of variance test (8). That is, we can reject the hypothesis that there is no significant difference in the group means (null hypothesis) with a very high degree of confidence. This analysis of variance test for the median pairs of trials gives an F of 4.66 with 3 and 50 degrees of freedom.

Another illustration of the relative difficulty of discrimination is shown in Table I, where it will be seen that the percent of animals in each group that reached the learning criterion differs markedly. For example, Group I shows only 30 percent of animals reaching the criterion while 92.8 percent of the animals in Group IV reached the criterion; the other two groups showed intermediate values.

IV. Discussion

It will be recalled that Hull (7) concluded from the time data of Grice's experiment with the long-short type of maze that animals would develop, because of the differential amount of work involved, a preference for the short path even though the temporal factor was completely equalized. The present investigation was specifically designed to test this conclusion and further to determine the functional relationship between rate of learning and the absolute value of the amount of 'work' involved in making the response.

Before continuing with a discussion of the results it is important to examine the time records of the animals to see to what extent the temporal factor was equalized. There is no *a priori* reason for assuming that the method of using two paths of equal length would insure that the times taken to make the alternative responses would be equal. In fact, it would seem reasonable to assume that time taken to obtain food by way of the path involving the greatest amount of pressure (weight) in depressing the lever would exceed that on the alternative path because of the differential work inhibition involved. This should be especially true for the groups run on absolute weight values which required considerable effort on the part of the animal in depressing the lever. Indeed, this proved to be the case as an analysis of the group means of the median reaction times of the *S*s showed. These data are presented in Table II.

TABLE II

The Group Means of the Median Reaction Time of the *S*s

Group	Path involving 'lighter' pressure	Path involving 'heavier' pressure
I.	8.49 sec.	7.67 sec.
II.	9.73 sec.	8.29 sec.
III.	6.84 sec.	8.68 sec.
IV.	7.07 sec.	11.40 sec.

The time differences in the case of Groups I and II are not statistically significant, while those for Groups III and IV are significant at the two percent and one percent levels of confidence, respectively. There would not appear to be a too close relationship, however, between these differences and the rate of learning of the various groups. Thus, Group II which had the second best learning record had the most unfavorable time difference, with the 'heavier' response actually averaging somewhat less time than the 'lighter' response.

Rank order correlations between the time ratios (heavy/light) and number of pairs of trials required by each *S* to learn lend further

support to the assumption that the time variable played little role in determining the learning differences. These coefficients were as follows: Group I, .20; Group II, .63; Group III, .42; and Group IV, .17. None of these correlations is significant except that for Group II, which is significant at the five percent level. While all are positive, they are quite inconsistent with the mean time data for the group. Thus, Group IV which showed the greatest difference in average time of taking the two paths gave the lowest correlation for the individual scores, while Group II with the highest correlation averaged longer on its 'lighter' responses than on its 'heavier' responses.

Although the present experimental situation did not achieve the desired goal of completely equalizing the temporal factor, we can, in view of the fact that the analysis showed that the learning was not significantly correlated with the times taken to run the paths, proceed on the assumption that the influence of this variable upon the results was negligible.

The data of the present experiment, then, would appear to support the conclusion that Hull drew from the Grice study, namely, that animals will develop a preference among two responses for the one involving the lesser amount of effort (work) even when the temporal factor is equalized. Certainly the results for Groups I and II support this conclusion.

The data indicate further that this preference will develop more rapidly when the absolute amount of work involved in the alternative responses is increased even though the work ratio of the two responses remains constant. Thus it will be seen from Fig. 2 that the median number of trials required to reach the learning criterion is not constant, but decreases as the absolute amount of work increases.

It is of some interest to examine the form of the curve in Fig. 2 in relation to the mathematical assumptions that Hull has made as to the development of work inhibition (I_R). In the postulate which introduces this construct Hull assumes that the cumulated work inhibition is a linear function of the number of trials or occurrences of the response (n), and furthermore that it is a positively accelerated function of the amount of work (W) involved in the performance of the response in question. The mathematical statement of this assumption is as follows:

$$I_R = \frac{cn}{B - W},$$

where c and B are empirical constants. The latter apparently represents the maximum amount of effort of which the organism is capable, e.g., the maximum weight it could depress in the present experiment,

while c is a parameter representing individual differences in the rate of development of work inhibition.

Now if it is assumed that the decisive factor in the choice of the two responses is the differential amount of work inhibition developed, we may determine the nature of the function relating the number of trials to learn to the amount of work (weight on the lever) in the following manner:

$$I_R \text{ (light weight)} = \frac{cn}{B - W}, \tag{1}$$

$$I_R \text{ (heavy weight)} = \frac{cn}{B - kW}. \tag{1a}$$

The difference, D, between the amount of inhibition cumulated for the two responses after any number of trials, n, of each would then be as follows:

$$D = \frac{cn}{B - kW} - \frac{cn}{B - W}. \tag{2}$$

Solving this equation for n we can obtain an equation which states the number of occurrences of each of the two responses as a function of the work variable. Thus:

$$D(B - kW)(B - W) = cn(B - W) - cn(B - kW)$$
$$D(B - kW)(B - W) = cn[(B - W) - (B - kW)]$$
$$n = \frac{D(B - kW)(B - W)}{c[(B - W) - (B - kW)]}$$
$$= \frac{A(B - kW)(B - W)}{(B - W) - (B - kW)}.$$

Where A is the constant $\frac{D}{c}$

$$= \frac{A(B - kW)(B - W)}{W(k - 1)}. \tag{3}$$

According to equation 3, n is a hyperbolic function of W. It may be seen that the results of the present experiment could be fitted fairly well by such a function. The small number of *S*s involved in the present experiment with the consequent unreliability of the experimental values and the relatively small number of experimental points do not justify, however, an attempt to fit these data with the above rational equation.

V. Summary

In the present experiment, the purpose of which was to determine the functional relationship between rate of learning and the absolute value of the amount of 'work' involved in making the response, four groups of rats were run in a learning situation consisting of a T-Maze and involving the operation of levers which required differential amounts of pressure. The animals were run at four different absolute weight values while the ratio between the weights required to depress the levers was kept constant (H/L = 1.5/1.0).

The results show that the effect of increasing the absolute weight values resulted in quicker learning. The differences are statistically significant at beyond the one percent level, as shown by an analysis of variance test.

An analysis of the time data shows that the learning was not significantly correlated with the times taken to traverse the paths. In view of this analysis the data were discussed in terms of 'work' inhibition.

Not only do the data appear to support Hull's deduction that in a situation involving two alternative responses animals will develop a preference for the one involving the lesser amount of effort when the temporal factor is equalized, but they indicate further that the development of this preference will proceed more rapidly when the absolute amount of work involved in the two responses is increased while the work ratio of the two responses is held constant.

The form of the empirical curve was examined in relation to Hull's mathematical assumption as to the development of work inhibition, and the nature of the function relating the number of trials to learn to the amount of work was mathematically determined. No attempt was made to fit the data with the derived rational equation in view of the small number of *S*s involved in the experiment.

(Manuscript received May 4, 1944)

Bibliography

1. Anderson, A. C. Time discrimination in the white rat. *J. comp. Psychol.*, 1932, **13**, 27–55.
2. Crutchfield, R. S. The determiners of energy expenditure in string-pulling by the rat. *J. Psychol.*, 1939, **7**, 163–178.
3. DeCamp, J. E. Relative distance as a factor in the white rat's selection of a path. *Psychobiol.*, 1920, **2**, 245–253.
4. Gengerelli, J. A. The principle of maxima and minima in animal learning. *J. comp. Psychol.*, 1930, **11**, 193–236.
5. Grice, G. R. An experimental study of the gradient of reinforcement in maze learning. *J. exp. Psychol.*, 1942, **30**, 475–489.
6. Heather, G. L. The avoidance of repetition of a maze reaction in the rat as a function of the time interval between trials. *J. Psychol.*, 1940, **10**, 359–380.

7. HULL, C. L. *Principles of behavior.* N. Y.: Appleton-Century, 1943.
8. LINDQUIST, E. F. *Statistical analysis in educational research.* New York, 1940, Houghton Mifflin.
9. TSAI, L. S. The laws of minimum effort and maximum satisfaction in animal behavior. *Monog. Nat. Res. Instit. Psychol.* (Peiping, China), 1932, No. 1. (See in *Psychol Abstr.*, 1932, 6, 4329.)
10. WATERS, R. H. The principle of least effort in learning. *J. gen. Psychol.*, 1937, 16, 3–20.
11. WHEELER, R. H. *The science of psychology.* N. Y.: Crowell, 1929.
12. WOLFE, J. B. The effect of delayed reward upon learning in the white rat. *J. comp. Psychol.*, 1934, 17, 1–21.
13. YOSHIOKA, J. G. Weber's law in the discrimination of maze distance by the white rat. *Univ. Calif. Publ. Psychol.*, 1929, 4, No. 10, 155–184.

CONTROLLED TEMPERATURES AND PRELIMINARY MEASURES OF MOTIVATION OF THE WHITE RAT

BY KENNETH MOORE

University of Kansas

Recent experiments have indicated that environmental temperature is an important condition of efficiency in maze learning of the white rat. Hellmer (**2**) has shown that rats living under 55° F. were two to three times more efficient in learning a simple maze than equal groups living at 90° F. An earlier paper by the author (**4**) also reported that the performance of the same group of rats changed as the temperature was varied under which they lived. Rats moved from a 55° F. to a 90° F. room showed a decrease in efficiency in maze learning, while similar groups moved from the higher to lower temperature showed a corresponding increase in maze learning. These experiments were concerned with establishing the direction and extent of differences in performance under different temperatures. The question of the importance of possible differences in motivation has so far not been considered. The purpose of the present paper is to report the results of preliminary measures of motivation taken from groups of rats which were tested for maze learning under controlled temperatures of 55°, 75°, and 90° F.

It is realized that most measures of motivation on an animal level are at best imperfectly valid. The problem becomes increasingly difficult in the present situation, where the different temperatures undoubtedly demanded different physiological adjustments on the part of the rat. The extent to which such factors enter into measures of intelligence or motivation is of course not yet determined. However, it was believed that certain objective measures, however tentative they might be, would eventually aid in clarification of the total pattern of changes elicited in response to differences in environmental temperatures.

The obstruction box method, with an electric grid between the food and rat, was used as one possible measure of motivation. As Ligon (**3**) has pointed out, the degree of punishment may well vary for different physiological states; therefore, elaborate precautions usually taken to insure exactly the same intensity shock to each rat crossing the grid were omitted. The main purpose was to introduce

a slight barrier between food and rat without involving too much physical activity. A relatively large number were tested in each room, and the results were considered only as a preliminary measure.

Loss of weight during grid tests and maze trials was used as a second test of possible differences in motivation, under the assumption that there might be a relationship between the two. Although the same schedule of food deprivation was followed in the three rooms, a possible higher rate of metabolism in the 55° F. room may have acted indirectly to produce differences in deprivation. Bruce (1) has suggested that the exact relation between food deprivation and motivation is still open to question. However, there is considerable evidence of a more or less direct relation between the two factors within the limits of the present conditions.

Standards of maze performance were first established and were reported in detail elsewhere. It is sufficient at this point to indicate that reliable differences in maze learning among similar groups of rats living in rooms kept at 55°, 75°, and 90° F. were found. Relearning tests 40 days later also showed significant differences in ability among rats in the three rooms. As in original learning, the advantage lay with the rats living at 55° F. As maze trials, grid tests, and weight records were kept for the same groups of rats, the following paragraphs outline the procedure followed throughout all three measures.

Procedure

Different temperatures were maintained in three experimental rooms. A refrigeration unit kept a constant temperature of 55–58° F. in the cold room. The hot room was equipped with an electric heater and thermostat which maintained a temperature of 88–90° F. The temperature of the third room (control room) varied with the temperature changes of the building, ranging from 75–79° F. during the experimental period. The relative humidity of the cold and hot rooms was kept approximately equal, varying from 50–75 percent saturation. Humidity changes in the control room varied over a slightly greater range. Food was kept before the rats in each room at all times, and all other conditions kept as nearly constant as possible.

At the age of four weeks, litters from the regular colony were divided equally among the three rooms. When 85 to 95 days old, approximately 45 rats in each room were tested for learning in a simple four-alley maze. After learning, equal groups on the basis of trials required to learn the maze were placed in each of the three rooms. Thus, from the group learning the maze in the cold room, 15 were left there, 15 were placed in the control room, and 15 were sent to the hot room. Similar division was made of the groups learning in the control and hot rooms. Relearning tests were made approximately 40 days later in each of the three rooms.

After relearning, each rat was tested in the same relearning room in an obstruction box. The apparatus was similar to that described by Warden (5). The starting and incentive chambers were 10 in. square, and were connected by a passageway 10 in. long and 4 in. wide and high. The floor of the passageway consisted of a removable sheet of bakelite. It was wound with number 26 uninsulated copper wire, so arranged that contact with any two adjacent wires completed the circuit. Current was furnished by a small induction coil placed outside the room. After preliminary trials with rats from the regular colony, the current was set at a voltage just strong enough to furnish a barrier which approximately half of the rats would cross frequently. This voltage was kept constant for all tests in the three rooms, and was checked for constancy every 10 min. The grid was kept clean and dry at all times. Two 40 watt lights above the inner partitions of the starting and incentive chambers furnished the illumination.

XUM

Each rat was first allowed two days of exploration in the grid before being tested. The rat was deprived of food for 36 hours before the first period of exploration. On the first day the rat was given 10 min. to investigate all parts of the box, followed by a 15 min. feeding period in the incentive chamber. The food, Gaines Dog Meal, mixed with enough milk to form a paste, was the same as used in the maze trials. On the second day each rat was given five preliminary crossings, with a 60 sec. feeding period after each crossing. After these practice trials, 10 min. additional feeding time was allowed. The test was made on the third day, but not until the rat had made three more preliminary crossings, securing a nibble of food after each trial. Current was then caused to flow in the grid, and records of approaches, contacts, and crossings for a 20 min. period were kept. This period was divided into four five min. intervals in order to obtain a more complete picture of behavior. Definite orientations toward the food, with the nose even with the connecting passageway, were considered as approaches. Contacts were counted when the rat touched the grid with nose or foot and received a shock. After each crossing, the rat was allowed to obtain only a small bite of food. It was then returned to the starting chamber and placed in different positions relative to the grid according to a systematic plan.

Daily weight records were kept for each rat during maze trials (both learning and relearning) and obstruction box tests. The rats were weighed at the time of isolation before trials were begun, and taken just before each day's trials in the maze or obstruction box. The records were continued until the rat had learned the maze or was given the final test on the grid.

Results

Obstruction box tests.—Approaches, contacts, and crossings of the grid were recorded for each five min. interval during the 20 min. test period. Means for these values are presented in Table I.

TABLE I

Means, Standard Deviations, and Standard Errors for Each Five Min. Period for all Rats Tested in Each Room

	47 rats tested in cold room			53 rats tested in control room			49 rats tested in hot room		
	Mean	σ	$\sigma/\sqrt{N}$	Mean	σ	$\sigma/\sqrt{N}$	Mean	σ	$\sigma/\sqrt{N}$
First 5 min.									
Approaches	3.6	9.15	1.33	5.1	3.64	.50	5.0	3.48	.50
Contacts	7.9	5.54	.81	8.1	5.21	.72	7.0	4.22	.60
Crossings	6.3	6.94	1.01	3.0	3.71	.50	1.9	6.23	.89
Second 5 min.									
Approaches	3.0	2.98	.43	3.9	3.55	.49	4.5	3.87	.55
Contacts	1.0	3.43	.50	1.4	3.64	.50	1.1	1.19	.17
Crossings	7.7	9.06	1.32	3.3	5.45	.75	1.7	3.36	.48
Third 5 min.									
Approaches	1.9	2.37	.35	2.6	3.14	.43	3.6	4.11	.59
Contacts	.7	1.16	.17	1.2	2.27	.30	.8	2.12	.30
Crossings	8.4	9.63	1.40	4.2	6.28	.86	2.2	4.28	.61
Fourth 5 min.									
Approaches	1.9	2.67	.39	3.2	4.41	.61	3.1	4.03	.58
Contacts	.7	1.49	.22	1.1	2.83	.39	.8	1.75	.25
Crossings	7.1	8.22	1.20	4.4	6.69	.92	2.5	3.96	.57
Totals									
Approaches	10.2	8.80	1.28	14.6	12.20	1.67	16.1	12.90	1.84
Contacts	10.3	6.70	.97	11.6	11.20	1.54	9.6	7.08	1.01
Crossings	29.5	29.80	4.32	14.8	20.45	2.81	8.1	11.90	1.70

More approaches but fewer crossings occurred during each interval in the hot room. Contacts were generally more frequent in the control room, while the greatest number of crossings always occurred in the cold room. The sigmas indicate that the greatest variability for approaches came in different periods for each room. In the cold room, it was during the first and second periods. The first and fourth intervals had the greatest variability in the control room, while it was the third and fourth in the hot room. Contacts showed almost the same order in all rooms, when variability was considered. On the other hand, for crossings, the third interval in the cold room, the fourth in the control, and the first in the hot room had the largest sigmas.

On the basis of total approaches, contacts and crossings, *t*-values were calculated. Comparison of the cold and control rooms gave values of 2.10 * for approaches, .71 for contacts, and 2.85 † for crossings. For differences between the cold and hot room, the ratios were 2.63,† .50, and 4.60 † for the three standards. For the control and hot rooms, the values for approaches, contacts, and crossings were .60, 1.09, and 2.04 * respectively. Thus, it seemed unlikely that there were significant differences between contacts in the three rooms, or in approaches between the control and hot rooms. Differences between crossings were large and statistically significant. Similar ratios for differences between rooms during each five min. interval were also examined, and a similar trend was observed. Approaches and contacts failed to show significant differences, but for the most part significant differences were found for crossings. Differences in crossing between the control and hot rooms were the least reliable.

The performance of sub-groups which were tested in the same room, but which learned the maze in different rooms, was also examined. No reliable or significant differences were found among the three sub-groups on any of the standards, either on the five min. or total 20 min. basis.

It will be remembered that the rats tested in the obstruction box had also relearned the maze in that same room. Coefficients of correlation were calculated to discover if there was any relation between the number of trials required for relearning and the frequency of grid crossing. The Pearson product moment method gave the following values: rats in the cold room, $r = +.064$, in the control room, $r = -.072$, and in the hot room, $r = -.303$. All of the r's were far below the five percent level of significance, and indicate little or no relation between grid crossings and relearning ability. Ex-

* Above the five percent level of significance.
† Above the one percent level of significance.

amination of performance on the basis of sub-groups in each of the rooms also revealed the same lack of relationship.

Weight losses and maze performance.—Weekly weight records kept throughout the experiment indicated that the mean weights of the rats in the three rooms differed significantly. In order to measure relative weight losses during maze trials, the mean percent original weight retained during each day of maze trials was determined. Table II gives these values for the rats learning the maze the first time.

TABLE II

MEAN PERCENT ORIGINAL WEIGHT RETAINED EACH DAY OF MAZE RUNNING FOR EACH ROOM

Day	Cold room				Control room				Hot room			
	No.	Mean	σ	$\sigma/\sqrt{N}$	No.	Mean	σ	$\sigma/\sqrt{N}$	No.	Mean	σ	$\sigma/\sqrt{N}$
1	34	92.7	2.54	.44	34	93.1	2.48	.43	39	92.2	3.11	.50
2	40	88.0	3.62	.62	42	89.4	3.07	.53	44	90.0	2.84	.46
3	39	86.0	4.50	.78	41	88.5	2.90	.51	45	89.4	3.68	.60
4	35	84.6	5.07	.90	37	87.7	4.28	.78	37	88.9	4.11	.72
5	31	84.9	5.56	1.13	30	89.0	4.08	.78	34	89.8	5.40	.98
6	22	85.0	5.74	1.32	24	90.2	5.21	1.14	30	89.7	5.92	1.14
7	12	83.2	5.70	1.72	17	89.8	5.33	1.33	23	91.0	7.14	1.64
8					16	90.3	5.50	1.47	20	91.5	6.44	1.61

Measured by this method, the cold room rats showed a steady loss of weight until the fourth day with stabilization at about 85 percent of their original weight, followed by a second short drop. The control and hot room values followed each other closely, and showed a tendency to increase after the fourth or fifth day. Although there were decided differences in maze performance between the hot and control rooms, this fact would not have been predicted by the weight losses. Examination of the sigmas indicated that about the same degree of variability was found in each room. The tendency for the sigmas to increase during the last days of maze running may have been due to the smaller number of rats still running the maze at that time.

The measures of reliability of the differences of the percent original weight retained in the three rooms are presented in Table III. Again, values of t were calculated.

Ratios for differences between the cold and control rooms, and the cold and hot rooms were large enough after the second day to indicate reliable differences. However, similar values for differences between the hot and control rooms do not approach the same level of significance. The same general trend was found when values for percent original weight retained during relearning were examined.

TABLE III

RELIABILITY OF DIFFERENCES BETWEEN MEAN PERCENT ORIGINAL WEIGHT RETAINED IN ORIGINAL LEARNING

Rooms	Days of maze trials							
	1	2	3	4	5	6	7	8
Cold-control.....	.65	1.73	2.67†	2.61*	2.99†	2.99†	3.04†	
Cold-hot.....	.76	2.60*	3.47†	3.74†	3.27†	2.70†	3.28†	
Control-hot.....	1.38	.86	1.17	1.09	.64	.31	.57	.50

* Above the five percent level of significance.
† Above the one percent level of significance.

The means corresponded closely with those found during original learning. Measures of the reliability of these differences were also made. The *t*-ratios for the cold and control rooms for the first and second days of maze running were 2.17 * and 3.45 † respectively. Similar values for the cold and hot rooms were 3.23 † and 5.27.† Ratios for the differences between the cold and hot rooms for the first three days of maze running were .95, 1.76, and 1.58. During relearning, however, significant differences in the number of trials required for relearning the maze were found in all three combinations, cold and control, cold and hot, and control and hot.

Weight losses and obstruction box tests.—The percent original weight retained during grid tests was also calculated, and means for this measure for the three rooms are presented in Table IV.

TABLE IV

MEAN PERCENT ORIGINAL WEIGHT RETAINED EACH DAY OF OBSTRUCTION BOX TESTS

	No.	First day			Second day			Third day		
		Mean	σ	$\sigma/\sqrt{N}$	Mean	σ	$\sigma/\sqrt{N}$	Mean	σ	$\sigma/\sqrt{N}$
Cold room.....	34	91.5	2.20	.38	88.3	2.53	.42	83.3	3.01	.50
Control room.....	36	93.1	2.41	.40	91.2	2.92	.49	86.7	3.00	.50
Hot room.....	36	93.0	2.40	.40	90.8	3.20	.53	88.0	2.98	.50

Smaller differences than in relearning trials were found in the weight losses of control and hot rooms. On the first day of food deprivation there was but little difference, while on the second day the control room rats retained more of their original weight than did hot room rats. Ratios indicating the reliability of the differences between mean weight losses each day were calculated. For differ-

ences between cold and control rooms on the first, second, and third days of grid tests, the *t*-ratios were 2.81,† 4.53,† and 5.02.† Corresponding values for differences between the cold and hot rooms were 2.38,* 3.83,† and 7.12.† No significant differences were found between the control and hot rooms. The *t*-ratios for the first, second, and third days were .15, .57, and 1.76 respectively.

The differences between performance and percent original weight retained in each room might well be summarized at this point. Significant differences in the number of trials required to learn the maze the first time were found among the three rooms. A corresponding significant difference between percent weight retained each day of maze trials was found after the first or second day between cold and control rooms, and cold and hot rooms, but none between control and hot rooms. The same pattern was repeated in the comparison of the obstruction box tests and weight losses. Significant differences in grid crossings between control and hot room groups failed to show up when percent original weight retained was considered.

Performance and mean weight loss per day.—Mean loss of weight per day for each rat during maze trials and grid tests was calculated. This was done in order to obtain a single measure of weight loss which could be compared with performance. The coefficients of correlation between mean loss of weight per day and performance in the maze and grid obtained by the Pearson product moment method are given in Table V.

TABLE V

CORRELATION BETWEEN MEAN LOSS OF WEIGHT PER DAY AND PERFORMANCE IN MAZE AND OBSTRUCTION BOX

	Trials original learning	Trials relearning	Crossings obstruction box
Rats tested in cold room.....	+.697†	+.243	+.180
Rats tested in control room....	+.573†	+.656†	+.097
Rats tested in hot room.....	+.395*	+.371*	−.001

* Above the five percent level of significance.
† Above the one percent level of significance.

It will be seen that a significant relation between mean daily weight loss and original learning was found. In relearning, however, the correlation between these same measures decreased considerably, and reached the one percent level of significance only in the control room. All three coefficients were quite small when grid crossings and daily weight losses were compared. Several factors may have been responsible for the lack of correlation between daily weight losses and grid crossings. The obstruction box as a measuring device may have been sensitive enough to show group, but not individual, differ-

ences. It is also possible that different aspects of motivation were measured by the obstruction box and weight losses, and these may not have changed in the same manner within each room.

If performance in the obstruction box is taken as a measure of motivation, then significant differences in this factor among the rats in the three rooms are evident. However, this relation was found to disappear when comparison of maze performance and grid crossings of individual rats within rooms was made. Somewhat the same trend was observed in the relation of weight losses and performance. Significant differences in percent original weight retained in original learning failed to show up among all of the three rooms in relearning or on the grid tests. Daily weight losses compared with performance repeated much the same pattern. On the basis of the measures reported in this paper, differences in motivation are strongly suggested. The evidence does not indicate, however, that all the observed differences in maze behavior can be reduced to motivation alone. These differences are but part of the total pattern of variables that must be considered in clarifying the relation between temperature changes and behavior.

Summary

Standards of maze performance for similar groups of white rats living under controlled temperatures of 55°, 75°, and 90° F. were determined in an earlier experiment. Measures of original and relearning ability were made, and in both tests reliable differences in ability were found among all three groups. In both cases, rats tested in the 55° room showed the best performance, those in the 90° room the poorest. In the present experiment, these standards were compared with two preliminary measures of motivation, loss of weight and the number of grid crossings in a simple obstruction box.

(1) It was found that there were significant differences in the total number of crossings in a 20 min. test period among the three groups of rats. Rats tested in the cold room averaged 29.5 crossings, those in the control room 14.8, and in the hot room, 8.1.

(2) There was little or no correlation between total grid crossings and maze performance (relearning) of the rats tested in any one room.

(3) Significant differences in the mean percent original weight retained during original maze learning were found between the cold and control rooms and the cold and hot rooms after the first two days. However, no such difference was found between the control and hot rooms. In original learning, reliable differences in the number of trials required to learn the maze were evident between the cold and control, cold and hot, and control and hot rooms.

(4) The same general trend was observed in differences in percent original weight retained during relearning. Reliable differences in percent weight retained were found for the cold and control and the cold and hot rooms, but not for the control and hot rooms. Maze performance in relearning differed significantly between each of the above combinations.

(5) Differences in percent original weight retained during grid tests did not correspond completely with grid crossings. Significant differences between control and hot room rats in grid crossings did not appear as similar differences in weight retained in these two rooms.

(6) Coefficients of correlation were calculated for the mean loss of weight per day and performance in the maze and on the grid. For the most part, a significant relation was found between mean daily weight loss and original learning ability. This relation dropped considerably when relearning ability was considered. Comparison of mean daily weight loss with grid crossings revealed little or no correlation.

(7) It is concluded that, on the basis of the measures of motivation here reported, there is a difference in the motivational factors involved in maze behavior in the three rooms. The evidence is not conclusive enough, however, to suggest that all differences in learning can be reduced to differences in motivation.

(Manuscript received May 15, 1944)

References

1. Bruce, R. H. The effect of lessening the drive upon performance by white rats in a maze. *J. comp. Psychol.*, 1938, 25, 225–248.
2. Hellmer, L. A. The effect of temperature on the behavior of the white rat. *Amer. J. Psychol.*, 1943, 56, 408–421.
3. Ligon, W. M. A comparative study of certain incentives in the learning of the white rat. *Genet. Psychol. Monogr.*, 1929, 2, No. 28, p. 95.
4. Moore, K. The effect of controlled temperature changes on the behavior of the white rat. *J. exp. Psychol.*, 1944, 34, 70–79.
5. Warden, C. J. *Animal motivation. Experimental studies on the albino rat.* Columbia Univ. Press, New York, 1931.

AMERICAN PSYCHOLOGICAL PERIODICALS

American Journal of Psychology—Ithaca, N. Y.; Cornell University. Subscription $6.50. 624 pages annually. Edited by K. M. Dallenbach, Madison Bentley, and E. G. Boring. Quarterly. General and experimental psychology. Founded 1887.

Journal of Genetic Psychology—Provincetown, Mass.; The Journal Press. Subscription $14.00 per annum (2 volumes). 1000 pages annually. Edited by Carl Murchison. Quarterly. Child behavior, animal behavior, and comparative psychology. Founded 1891.

Psychological Review—Northwestern University, Evanston, Illinois; American Psychological Association, Inc. Subscription $5.50. 540 pages annually. Edited by Herbert S. Langfeld. Bi-monthly. General psychology. Founded 1894.

Psychological Monographs—Northwestern University, Evanston, Illinois; American Psychological Association, Inc. Subscription $6.00 per volume. 500 pages. Edited by John F. Dashiell. Without fixed dates, each issue one or more researches. Founded 1895.

Psychological Bulletin—Northwestern University, Evanston, Illinois; American Psychological Association, Inc. Subscription $7.00. 665 pages annually. Edited by John E. Anderson. Monthly (10 numbers). Psychological literature. Founded 1904.

Archives of Psychology—New York, N. Y.; Columbia University. Subscription $6.00 per volume. 500 pages. Edited by R. S. Woodworth. Without fixed dates, each number a single experimental study. Founded 1906.

Journal of Abnormal and Social Psychology—Northwestern University, Evanston, Illinois; American Psychological Association, Inc. Subscription $5.00. 560 pages annually. Edited by Gordon W. Allport. Quarterly. Founded 1906.

Journal of Educational Psychology—Baltimore, Md.; Warwick & York. Subscription $6.00. 720 pages annually. Edited by J. W. Dunlap, P. M. Symonds, and H. E. Jones. Monthly except June to August. Founded 1910.

Psychoanalytic Review—New York, N. Y.; 64 West 56th St. Subscription $6.00. 500 pages annually. Edited by Smith Ely Jelliffe. Quarterly. Founded 1913.

Journal of Experimental Psychology—Northwestern University, Evanston, Illinois; American Psychological Association, Inc. Subscription $7.00 per annum. 520 pages annually. Edited by Samuel W. Fernberger. Bi-monthly. Founded 1916.

Journal of Applied Psychology—Northwestern University, Evanston, Illinois; American Psychological Association, Inc. Subscription $6.00. 480 pages annually. Edited by Donald G. Paterson. Bi-monthly. Founded 1917.

Journal of Comparative Psychology—Baltimore, Md.; Williams & Wilkins Co. Subscription $7.00 per annum (1 volume). 500 pages annually. Edited by Roy M. Dorcus. Bi-monthly. Founded 1921.

Comparative Psychology Monographs—Baltimore, Md.; Williams & Wilkins Co. Subscription $6.00 per volume. 400 pages. Edited by Roy M. Dorcus. Without fixed dates, each number a single research. Founded 1922.

Genetic Psychology Monographs—Provincetown, Mass.; The Journal Press. Subscription $7.00. 500 pages annually. Edited by Carl Murchison. Bi-monthly. Each number one complete research. Child behavior, animal behavior, and comparative psychology. Founded 1925.

Psychological Abstracts—Northwestern University, Evanston, Illinois; American Psychological Association, Inc. Subscription $7.00. 700 pages annually. Edited by Walter S. Hunter. Monthly. Abstracts of psychological literature. Founded 1927.

Journal of General Psychology—Provincetown, Mass.; The Journal Press. Subscription $14.00 per annum (2 volumes). 1000 pages annually. Edited by Carl Murchison. Quarterly. Experimental, theoretical, clinical, and historical psychology. Founded 1927.

Journal of Social Psychology—Provincetown, Mass.; The Journal Press. Subscription $7.00. 500 pages annually. Edited by John Dewey and Carl Murchison. Quarterly. Political, racial, and differential psychology. Founded 1929.

Psychoanalytic Quarterly—Albany, N. Y.; 372–374 Broadway. Subscription $6.00. 560 pages annually. Edited by Bertram D. Lewin and others. Quarterly. Founded 1932.

Character and Personality—Durham, N. C.; Duke University Press. Subscription $2.00. 360 pages annually. Edited by Karl Zener. Quarterly. Founded 1932.

Journal of Psychology—Provincetown, Mass.; The Journal Press. Subscription $14.00 per annum (2 volumes). 800–1200 pages annually. Edited by Carl Murchison. Quarterly. Founded 1936.

Psychometrika—University of Chicago, Chicago, Ill.; Psychometric Society. Subscription $10.00. 320 pages annually. Edited by L. L. Thurstone and others. Quarterly. Quantitative methods in psychology. Founded 1936.

Psychological Record—Bloomington, Ind.; Principia Press. Subscription $4.00. 500 pages annually. Edited by J. R. Kantor and C. M. Louttit. Without fixed dates, each number a single research. General psychology. Founded 1937.

Journal of Consulting Psychology—Lancaster, Penn.; Science Printing Co. Subscription $3.00. 240 pages annually. Edited by J. P. Symonds. Bi-monthly. Founded 1937.